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THE

STEAM-ENGINE

THEORETICALLY AND PRACTICALLY

DISPLAYED.

BY

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AND

HENRY AND JAMES ADCOCK,

CIVIL ENGINEERS.

ILLUSTRATED BY

A SERIES OF SPLENDID ENGRAVINGS

FROM

WORKING DRAWINGS MADE EXPRESSLY FOR THIS PUBLICATION.

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ADDRESS.

The rapid progress of mechanical discovery, and the acknowledged wants of the practical engineer, have suggested the work now offered to the public. Of the Steam-engine, the most wonderful of human inventions, no delineation comprehending its most recent forms and applications has yet appeared; whilst all the graphic displays of the earlier constructions have been deficient alike in accuracy and detail. The explanations have been also exceedingly imperfect; neither conveying an adequate account of the actual performance of each kind of machine, so as to direct the choice of the inquirer, nor such measures of the various parts of engines of different powers, as to supply that information which might enable the artist readily to construct them. In the present publication these deficiencies will be completely obviated; and it will, consequently, form a manual or guide for the machinist, the manufacturer, the merchant, the statesman, and the philosopher.

A knowledge of the properties of steam being essential to the theoretical elucidation of the Steam-engine, the first part of the work will convey a copious, yet concentrated account of this agent, derived from the writings of the most able experimentalists. But the relative powers of steam, produced under pressure much greater than that of the atmosphere, not having been hitherto satisfactorily determined, a second dissertation, devoted to this subject, will afterwards be introduced. An extensive series of experiments, which we have projected, was designed to supply the information requisite for this discussion: these experiments however will be deferred,

THE

STEAM-ENGINE.

INTRODUCTORY DISSERTATION ON STEAM.

Of the moving powers furnished by nature, water is the most useful and the most extensively employed. By the declivity of the surface over which it flows, in a few places favourably situated, it is enabled to exert a steady gravitating, or impelling force, of considerable extent: but exercising the elastic energy which it derives from combination with caloric, it may be pronounced to be a prime mover, at once universal and irresistible. Where the valuable mineral coal abounds, this wonderful agent may of course be most advantageously applied; but the interminable forests with which several vast portions of the globe still continue to be clothed, will, ere long, be made to contribute an efficient and adequate supply of this astonishing instrument of modern civilization.

With the intimate nature of caloric we still remain unacquainted. We know from abundant evidence, that when it penetrates matter in every state of aggregation, the dimensions of such matter become increased. Expansion, therefore, is said to be one of its most general properties. This enlargement of volume, water experiences in common with all other bodies; but after a certain period minute

portions only expand further, and that with suddenness and to a much greater extent. These globular portions of caloric and water are first descried near the bottom of the vessel, where, indeed, the caloric generally enters; they rise partly through the fluid, and vanish, but afterwards they expand through the whole depth, lifting up the atmosphere by which the fluid is pressed, and disappear at its surface. If caloric continue to flow into the water, this peculiar expansion proceeds more rapidly, and the whole mass is thrown into a state of confused but active agitation. This process is called *ebullition;* the point of the thermometrical scale at which it occurs, the *boiling point;* and the agitating cause, *aqueous vapour* or *steam.*

As it is necessary for the spherule of vapour to ascend through the water of which it made a part, in opposition to the weight of the atmosphere, it must be obvious that the time of its formation, and the quantity of caloric required, will be varied by differences in this weight. Some fluids, alcohol and ether for example, have always a temperature such, that, when relieved from this pressure, they instantly assume a gaseous form: and water at 88 degrees of Fahrenheit's thermometer, if placed in the vacuum of an air-pump, will also begin to boil. On the other hand it is well known, that if water be confined in vessels which are close and strong, it may be heated much higher than 212°. the temperature of ebullition under ordinary circumstances: the elasticity is now resisted by the surrounding substance, and until an opening is provided, although more caloric be introduced, the developement of vapour is impracticable. The relation of temperature, pressure, and elasticity, now hinted at, will be fully displayed in the progress of this dissertation; ample materials having been provided by Watt, Southern, Robison, Dalton, Clement,

Taylor, and Ure. The arrangement and comparison of their experiments and conclusions, has become necessary on account of their number and occasional discrepancy, and is indeed at the present time essential to the complete theoretical illustration of the steam-engine.

Aqueous vapour in its perfect state, is transparent and colourless, consequently invisible. We are chiefly accustomed to attend to it, when having partially mingled with the air, or having touched substances cooler than itself, it has become vesicular, and consequently visible. The moist white vapour, therefore, composed of an infinite number of vesicles or small globules, is not, as generally supposed, perfect steam, but steam which has been robbed of a portion of caloric. The consequence of this abstraction of caloric is the loss of the gaseous or elastic form, and is quickly followed by a complete restitution of the state of inelastic fluidity. The facility and suddenness, indeed, with which condensation, as this change is denominated, may be effected by different refrigerating means, is a property not less remarkable or important than elasticity, the energetic property which we have already mentioned.

Water exposed in an open vessel to the action of fire cannot, however great the heat applied, be made to indicate a higher temperature than that which first produces ebullition. Steam will be evolved in greater or less abundance, according to the heat applied, but throughout the process its temperature will continue the same as that of the water. Doctor Hooke directed our attention to this fact; but to Dr. Black is due the honour of having first minutely investigated the whole phenomenon. He discovered, that during the conversion of ice into water, a greater quantity of caloric

disappeared than was indicated by the thermometer; therefore, reasoning from analogy, he was led to conclude, that as the difference between a liquid and a solid is ascribable to the fixation of caloric, so, most probably, an elastic fluid, such as steam, differs from a liquid, such as water, in consequence of the operation of the same cause. In endeavouring to ascertain this point, he compared the time of raising the temperature of a liquid a certain number of degrees with the time of evaporating it by the same influx of external heat, and found, that the caloric existing in a latent state in steam which balances the pressure of the atmosphere, was not less than 800 degrees. Subsequent experiments performed by other philosophers seem to prove, that the heat which disappears is here stated too low; but it must be confessed that the results of the experiments on this interesting subject exhibit great discrepancies.

Latent Heat of Aqueous Vapour.

	Fahrenheit.		Fahrenheit.
Black - - - -	800°	Clement - - -	990°
Ure - - - -	888	Lavoisier - - -	1000
Southern - - -	945	Thompson - - -	1016
Watt - - - -	950	Rumford - - -	1021

Considering that the caloric producing these important changes was not immediately discoverable by the thermometer or the senses, Dr. Black gave it the name of LATENT HEAT. Subsequently it has been termed by Professor Pictet, with more propriety, caloric of fluidity, and caloric of vaporization.

From the well-known ability and long experience of the late James Watt, we ought to conclude, that the result of his experiments approaches very near the truth; more especially as it coincides with

that of Southern, who in practical dexterity was very little, if at all, inferior to his highly ingenious and scientific friend.

It was in the course of the year 1781,* that Mr. Watt tried experimentally to ascertain this point. He obtained a pipe of copper, one-fiftieth of an inch thick, five feet long, and five-eighths of an inch diameter in the bore, and having bent the extremities in contrary directions, fixed one end steam-tight, on the spout of a tea-kettle, from which the pipe inclined upwards, so that the other end was about two feet higher than the spout. In the upper end was fitted a piece of cork, having a hole about two-tenths of an inch diameter, and a small piece of quill introduced to keep the perforation open. The kettle was filled with water half way up the spout, and the lid, being made tight with a proper lute, was securely held down by a piece of wood, reaching from the top of the centre of the lid to the under side of the handle. It was placed over a fire and made to boil, and care was taken to allow the steam to escape, until such portion of it as condensed, no longer dropped from the end of the tube but returned by the inclined part into the kettle. A tin pan, four inches deep and six inches in diameter, was supplied with 2½ lbs avoirdupois of water, then weighed with great accuracy, and placed on several folds of flannel on a stand. This stand was made of sufficient height to allow the extremity of the cork in the upper end of the tube to be immersed in the water in the pan. The water was nearly 2½ inches deep. A disk of strong paper, smeared with linseed oil and dried, was fitted to the inside of the pan; and it was again accurately weighed.

When the end of the tube was immersed in the cold water of the

* Professor Robison's Mechanical Philosophy.

pan, the steam issuing from it was condensed with a crackling noise, and the water became heated. The water was constantly stirred that the heat might be equally distributed, and the experiment was continued until the water had acquired from 70 to 90 degrees of heat, which was generally in from four to six minutes. Afterwards the pan was covered with a disk of oiled paper, to prevent evaporation, which would have lessened the weight during the operation of weighing. The heat of the room, during the experiments, was generally about 56 degrees.

Having so far completed the preparation, it became necessary, in order to obtain the greatest possible accuracy, to learn what quantity of heat had been absorbed by the pan. It was therefore made quite dry, and placed in a room of the temperature 40°; and in about half an hour, when it was supposed to have acquired the heat of the place, 2 lbs of water, of the temperature 76°, were poured into it. The result was 75½°. Then for every 35½° with 2 lbs of water, or every 44° with 2½ lbs of water, half a degree must be allowed for the heat absorbed by the pan.

Eleven experiments were made by Mr. Watt, from which the latent heat of steam has been calculated according to the following example. The heat of the water in the pan at the beginning of the experiment was 43·5, at the conclusion 89·5; so that, by the condensation of the steam, the water in the pan gained 46 degrees of heat. The quantity of water in the pan at the beginning of the experiment was 17500 grains, at the end 18260, therefore the effect was produced by the condensation of a quantity of vapour, equal to 760 grains. By multiplying the quantity of water in the pan at the beginning of the experiment, by the increase of

temperature from the condensed steam, and by the heat absorbed by the pan, we have $17500 \times 46^\circ \times 0{\cdot}5 = 81375$; and by dividing this product by the weight of condensed steam, and adding to the quotient the heat of the mixture, we have $81375 \div 760 + 89{\cdot}5 = 1159{\cdot}5$, the sum of the sensible and latent heats. The sensible heat 212° being deducted, leaves 947·5 as the latent heat of steam. In a similar manner, Mr. Watt determined the particulars of the other experiments, the results of which are exhibited in the following table:—

No. of the Experiment.	Quantity of cold Water in Pan in Grains.	Temperature of the cold Water.	Weight of condensed Steam in Grains.	Temperature of the heated Water.	Increase of Heat.	Total sensible and latent Heat.	Latent Heat.
1	2	3	4	5	6	7	8
1	17500	43°5	760·	89°5	46°5	1159°5	947°5
2	17500	44·5	708·	86·5	42·5	1136·9	924·9
3	17500	44·5	899·	98·	54·	1149·1	937·1
4	17500	44·5	467·5	73·5	29·5	1175·6	963·6
5	17500	44·5	369·	67·25	23·	1158·	946·
6	17500	47·5	642·	87·	40·	1177·3	965·3
7	17500	49·	588·5	84·5	36·	1155·	943·
8	17500	47·	675·	87·5	41·	1150·5	938·5
9	17500	45·	680·5	86·5	42·	1166·5	954·5
10	17500	45·	664·25	85·5	41·	1165·66	953·66
11	17500	45·	975·	102·	57·5	1134·	922·

The sum of the quantities in the eighth column divided by the number of experiments gives 945°·03 as the average; but if the second and eleventh experiments, which yield results much smaller than the others, and which Mr. Watt therefore considered objection-

able, be omitted, the average will be 949°·9. As several circumstances however affect these experiments, tending for the most part to make the latent heat appear rather less than it actually is, Mr. Watt considers that we shall not err in excess by calling it 960 degrees.

One of the circumstances productive of the error above alluded to, is the progressive increase or diminution of caloric by radiation, and by the contact of the surrounding atmosphere. This interference with his conclusions, neglected by Mr. Watt, was averted in a very ingenious and satisfactory manner by Count Rumford. At the commencement of his experiment, he rendered the temperature of his apparatus ten or twelve degrees lower than that of the surrounding air; and the vapour was then allowed to pass into the tube of the refrigeratory. Whilst the temperature of the water around the tube continued below that of the air and adjacent bodies, caloric flowed into it, and it was consequently warmed by them. But the contrary effect occurred of course, when the circumstances as to temperature were reversed; the surrounding bodies being warmed by the apparatus. Conducting his experiment therefore in such manner, that the same time was occupied in each case, a compensation was obtained, the same quantity of caloric being retained by the whole apparatus, as if no portion had been either absorbed or emitted. It is to this ingenious precaution, chiefly, that Biot is disposed to ascribe the superior accuracy of Rumford's experiments; and the agreement of their results with those of the profound investigator, Gay-Lussac.

We have already intimated that the experimental results of Watt and Southern very nearly coincide. Mr. Southern's experiments were performed in 1803 with the intention of ascertaining the latent

heat of steam under three degrees of elasticity, viz. equal to the support of 40, 80, and 120 inches of mercury. The following are the results brought into a tabular form.

No. of Experiment.	Duration of the Experiment.	Weight of cold Water in pounds.	Temperature of cold Water.	Temperature at the End of Experiment.	Temperature gained.	Weight of Water gained.	Temperature of Steam.	Elasticity of Steam in inches.
1	2	3	4	5	6	7	8	9
		lbs.				lbs.		Inches.
1	12′·45″	$28\frac{1}{2}$	48°	80°	32°	,878	229	40
2	5·50	$28\frac{1}{2}$	48	$81\frac{1}{3}$	$33\frac{1}{3}$	,857	270	80
3	4·00	$28\frac{1}{2}$	$47\frac{3}{4}$	81	$33\frac{1}{4}$	,826	295	120

From the above experiments may be calculated the latent heat of the steam formed in each. For, if the weight of the water which received the heat be multiplied by the number of degrees of temperature communicated to it, and the product be divided by the accession of weight to the water, the quotient will give the caloric which the steam lost. By adding to this the temperature of the water in the vessel at the conclusion of the experiment, a number will be obtained showing the *whole heat*, or the *sum* of the sensible and latent heat of the steam. Hence, by subtracting the sensible heat of the steam from this sum, the latent heat will be found. Thus $\frac{\text{col } 3 \times \text{col } 6}{\text{col } 7} + \text{col } 5 =$ the sum of the sensible and latent heat; or if

$W =$ weight of cold water, $T =$ its temperature,

$w =$ accession of water by the condensed steam,

t = temperature of warm water, and

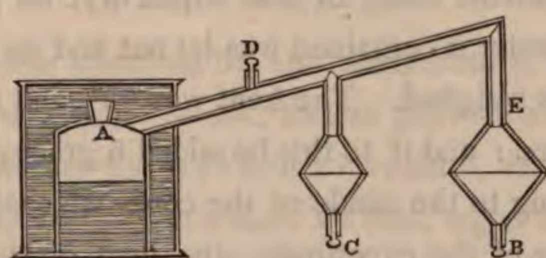
x = sum of the sensible and latent heat of the steam condensed.

$$\frac{\overline{W + w} \,.\, t - W\,T}{w} = x.$$

If in either of the above equations the quantities found in the preceding table be properly employed, the sums of the sensible and latent heat will be 1119°, 1190°, and 1228°; and the latent heat 890°, 920°, and 933°. It was distinctly observed, however, that the tin vessel in which the steam was generated imparted heat to the surrounding air: and an experiment was made to determine the amount of this loss. It was found when the contained water was at 80°, 1° was lost in five minutes; and when at 60°, 1° was lost in $10\frac{1}{2}$ minutes; it would therefore, probably, lose 1° in 8 minutes during the time of performing an experiment—the mean temperature being about 65°. As the excess of temperature at the beginning and end of each experiment above that of the air was nearly the same in all, the loss would be nearly proportional to the duration of each: hence, to the acquired heat should be added, in the first experiment, $1\frac{5}{8}$°; in the second, $\frac{3}{4}$°; and in the third, $\frac{1}{2}$°; being severally proportional to the said duration. These being respectively added to the temperatures in cols 5 and 6, give in the former $81\frac{5}{8}$°, 82°, and $81\frac{1}{2}$°; and in the latter $33\frac{5}{8}$°, 34°, and $33\frac{3}{4}$°; and if either of these sets of numbers be used in the calculation, according as one or the other of the equations is adopted to develope the results, they will be found to be 1171°, 1212°, and 1245°, for the sums of the sensible and latent heat; and consequently the latent heat in each experiment will be 942°, 942°, and 950°.

During Mr. Watt's residence in Glasgow, in 1765, he instituted a series of experiments to ascertain what quantity of heat is latent in steam when produced by the distillation of water in vacuo. Dissatisfied with the result of those experiments, he, in 1783, renewed the investigation.

A small still, A, surrounded by a water-bath, was made of tin plate and communicated by a pipe with the two double cones, B and C. Each of these cones had a small opening in its lower apex, made air-tight by a brass plug. A similar opening, shut in the same manner, was



in the tube at D; and the conical mouth of the still, A, was closed by a good cork. A pint of water was poured into the inner vessel, and as much into the outer one, and the whole was set upon a chafing-dish, and made to boil. At first, the steam was allowed to issue through B and C, and when it was supposed that all the air was expelled, the aperture C was shut, and immersed sufficiently in water to prevent the air from re-entering. After this, the steam was allowed to escape some time longer through B, when that was also shut and similarly immersed to a small depth in water. Cold water was poured into the bath, to cover the orifice and its cork, and a degree of exhaustion was instantly produced in the internal vessel, and in the two double cones communicating with it.

The double cone, B, was then wholly immersed in a tin pan, 6 inches deep and $8\frac{1}{4}$ inches diameter, filled to within an inch of its mouth with cold water, weighing 130 ozs. 16 dwts. 16 grs.* troy, or 62800 grs. The heat of the water at the beginning of the experiment was 52°, or, more accurately, 51°·75. When it was supposed that a sufficient quantity of water had distilled into the receiver, B, the heat of the water in the pan, or refrigeratory, was 61°, exhibiting an increase of temperature of 9°, or rather $9\frac{1}{4}$°. The plug at D was now withdrawn, the air admitted, and the refrigeratory removed. The double cone, B, was wiped dry, its plug was withdrawn, and the water it contained was let out and its heat examined, and finally it was weighed. The heat was 62°, and its weight 1 oz. 54 grs., or 534 grs.: and if to this be added 6 grs. by estimation, for the water adhering to the inside of the cone, we shall have 540 grs. At the beginning of the experiment, the heat of the water in the bath was 134°, at the end 158°; consequently, one-third part of air or other elastic vapour remained in the still and receiver. The refrigeratory was prevented from being affected by the chafing-dish by a screen of bricks. The heat of the air in the room was about 58°, and the duration of the experiment was 9 minutes. The double cone, B, weighed 1000 grs. Its heat at the beginning of the experiment was 134°, and at the end 62°, the refrigeratory producing a loss of 72°. Its specific gravity was probably $7\frac{1}{2}$ times that of water: hence its bulk that of $\frac{100}{75} = 134·6$ grs. of water. Its capacity for heat being about three-fourths of that of the same bulk of water, it

* In Mr. Watt's account of these experiments, the weight of cold water is 130 ozs. 6 drs. 40 dwts.; but this we consider to be a typographical error, as it is confounding apothecaries' with troy weight.

would contain the same quantity of heat as about 101 grs. of water; and this heat, not having been communicated by the condensed steam contained in the cone at the end of the operation, should be deducted from the heat acquired by the water in the refrigeratory, or, which produces the same result, 101 grs. should be deducted from its weight. The results of the experiment may be stated as follows:

	Grs.
Weight of water in the refrigeratory - - - -	62800
From this deduct 101 grs. as the equivalent for the bulk of the cone - - - - - - - - -	101
	62699
And add the heat absorbed by the refrigeratory, which was of tin, and weighed $24\frac{1}{2}$ ozs., less an allowance to be deducted of $4\frac{1}{2}$ ozs. for the wire round its mouth, and other parts not in contact with the water, 20 ozs., equal in bulk to about 1320 grs. of water. But as its capacity for heat is only two-thirds that of water, it will really be only equal to 980 grs., which must be added to the water in the refrigeratory - - - - - - - - -	980
Total weight of water, &c. heated - -	63679
This multiplied by 9°·25, the heat acquired, yields 589030·75, and this divided by the weight of condensed steam = 540 grs. gives - - - - - -	1090
And if to this be added the heat retained - - -	62
We shall have for the sum of the sensible and latent heat	1152
From which deducting the average sensible heat of the steam - - - - - - - - - -	146
We have for the latent heat - - - - -	1006

Accurate as these experiments may seem to be, Mr. Watt was not fully satisfied with them. He saw that several things which he had determined by calculation ought to have been ascertained by experiment, and that the degree of exhaustion was not so great as it ought to have been, or as he had obtained it in other experiments. The cone, B, should have had a slip joint in its neck, at E, by which it could have been taken off and weighed before and after each experiment, in order that he might have been able to ascertain what quantity of water adhered to the inside. Its specific gravity should also have been determined by weighing it in water, and its capacity for heat accurately examined. The cone, C, was intended to receive any water that might flow over in consequence of violent ebullition; but as the still was cooled sooner than the cones, that effect did not take place, and this cone might be omitted in future experiments. Mr. Watt states, that he would most probably have rendered the vacuum more complete, by repeatedly boiling the water, condensing the steam, and blowing out the air, until the distillation should have taken place at 70° or 80°; but he was called away from prosecuting the experiment at that time by business, and had not his attention drawn to it after that period.

Mr. Watt and Mr. Southern state that the caloric latent in steam is a constant quantity, but Mr. Herepath maintains that the results have been materially influenced by variations in the proportion of the quantity of steam condensed, and of the quantity of water employed for its condensation. This opinion seems to accord with the calculations which he performs by means of a theorem, introduced for the purpose of establishing some ingenious speculative

notions respecting calorific capacity, and the true temperature. It also in some instances agrees with the actual results. In the experiments of Dr. Ure the steam and water were in the proportion of 1 to 161·7, and the result was 888°; whilst in one experiment performed by Count Rumford, it was that of 1 to 114, with a result of 1018°, and in a second of 1 to 96·1, the latent heat appearing to be 1023 degrees.

From all the experiments to determine the quantity of heat latent in steam, notwithstanding their partial disagreement, it is evident, that though steam produced under the ordinary pressure of the atmosphere does not indicate a higher temperature than boiling water, or about 212°, it does actually contain nearly 1200 thermometric degrees of heat. Steam, therefore, when mixed with six times its weight of water at 32°, will raise its temperature to 212 degrees; and it is on this account employed in several brewhouses, dyeing works, and manufactories where large quantities of hot water are required. Many large buildings are also warmed by steam; and it is very advantageously employed in several drying processes where great heat is required, and where the substances to be heated are liable to combustion.

To the latent heat thus existing in water when converted into steam, or to the caloric of vaporization, its elasticity is ascribable. Speculation has been active in endeavouring to show how this property is conferred by caloric, but hitherto without effect. Experiment has been more successful in ascertaining the extent of this elasticity; a subject of great practical importance. Many scientific individuals, as before stated, have directed their attention to this inquiry, and the results of their investigations will be found in the following copious synopsis.

SYNOPSIS OF EXPERIMENTAL AND CALCULATED RESULTS ON THE ELASTICITY OF VAPOUR.

Temperature.			Force in Inches of Mercury.									
Fahrenheit.	Reaumur.	Centigrade.	Robison, by Experiment.	Dalton, by Experiment.	Ure.		Creighton, by Calculation.	Watt, by Experiment.	Southern.		Taylor, by Experiment.
					By Experiment.	By Calculation.			By Experiment.	By Calculation.	
32°	0	0	0·0	0·200	0·200	0·200	0·200	..	0·160	0·180	..
33	0·44	0·55	..	0·207	..	..	..	..	..	..	..
34	0·88	1·1	..	0·214	..	..	..	..	..	..	..
35	1·33	1·66	...	0·221	..	..	..	..	..	..	..
36	1·77	2·22	..	0·229	..	..	..	..	..	..	..
37	2·22	2·77	..	0·237	..	..	..	..	..	..	..
38	2·66	3·33	..	0·245	..	..	...	..	..	..	..
39	3·11	3·88	..	0·254	..	..	..	..	..	..	..
40	3·55	4·4	0·1	0·263	0·250	0·280	0·260	..	..	..	..
41	4·00	5·00	..	0·273	..	..	..	..	..	..	..
42	4·44	5·55	..	0·283	..	..	..	..	0·230	0·250	..
43	4·88	6·11	..	0·294	..	..	..	..	..	..	..
44	5·33	6·66	..	0·305	..	..	..	..	..	..	..
45	5·77	7·22	..	0·316	..	..	..	..	..	..	..
46	6·22	7·77	..	0·328	..	..	..	..	..	..	..
47	6·66	8·33	..	0·339	..	..	..	..	..	..	..
48	7·11	8·88	..	0·351	..	..	..	..	..	..	..
49	7·55	9·44	..	0·363	..	..	..	..	..	..	..
50	8·00	10·00	0·2	0·375	0·360	0·400	0·350	..	..	..	..
51	8·44	10·55	..	0·388	..	..	..	..	..	..	..
52	8·88	11·11	..	0·401	..	..	..	..	0·350	0·350	..
53	9·33	11·66	..	0·415	..	..	..	..	..	..	..
54	9·77	12·22	..	0·429	..	..	..	..	..	..	..
55	10·22	12·77	..	0·443	0·416	..	..	0·150	..	..	..
56	10·66	13·33	..	0·458	..	..	..	..	..	..	..
57	11·11	13·88	..	0·474	..	..	..	..	..	..	..
58	11·55	14·44	..	0·490	..	..	..	..	..	..	..
59	12·00	15·00	..	0·507	..	..	..	..	..	..	..
60	12·44	15·55	0·35	0·524	0·516	0·560	0·500	..	..	..	..
61	12·88	16·11	..	0·542	..	..	..	..	..	..	..

SYNOPSIS, *&c.—continued.*

Temperature.			Force in Inches of Mercury.								
Fahrenheit.	Reaumur	Centigrade.	Robison, by Experiment.	Dalton, by Experiment.	Ure. By Experiment	Ure. By Calculation.	Creighton, by Calculation.	Watt, by Experiment.	Southern. By Experiment.	Southern. By Calculation.	Taylor, by Experiment.
62°	13°·33	16°·66	..	0·560	..	..	..	..	0·520	0·500	..
63	13·77	17·22	..	0·578	..	..	..	..	..	..	..
64	14·22	17·77	..	0·597	..	..	..	..	..	..	..
65	14·66	18·33	..	0·616	0·630	..	..	..	..	..	..
66	15·11	18·88	..	0·635	..	..	..	..	..	..	..
67	15·55	19·44	..	0·655	..	..	..	..	..	..	..
68	16·00	20·00	..	0·676	..	..	..	..	..	..	..
69	16·44	20·55	..	0·698	..	..	..	..	..	..	..
70	16·88	21·11	0·55	0·721	0·726	0·770	0·690	..	..	..	..
71	17·33	21·66	..	0·745	..	..	..	..	..	..	..
72	17·77	22·22	..	0·770	..	..	..	..	0·730	0·710	..
73	18·22	22·77	..	0·796	..	..	..	..	..	..	..
74	18·66	23·33	..	0·823	..	..	..	0·650	..	..	..
75	19·11	23·88	..	0·851	0·860	..	..	..	..	..	..
76	19·55	24·44	..	0·880	..	..	..	..	..	..	..
77	20·00	25·00	..	0·910	..	..	..	..	..	..	..
78	20·44	25·55	..	0·940	..	..	..	..	..	..	..
79	20·88	26·11	..	0·971	..	..	..	..	..	..	..
80	21·33	26·66	0·82	1·00	1·01	1·06	·970	..	..	..	..
81	21·77	27·22	..	1·04	..	..	..	·0800	..	..	..
82	22·22	27·77	..	1·07	..	..	..	..	1·02	1·01	..
83	22·66	28·33	..	1·10	..	..	..	..	..	..	..
84	23·11	28·88	..	1·14	..	..	..	..	..	..	..
85	23·55	29·44	..	1·17	1·17	..	..	..	..	..	..
86	24·00	30·00	..	1·21	..	..	..	..	..	..	..
87	24·44	30·55	..	1·24	..	..	..	..	..	..	..
88	24·88	31·11	..	1·28	..	..	..	..	..	..	..
89	25·33	31·66	..	1·32	..	..	..	..	..	..	..
90	25·77	32·22	1·18	1·36	1·36	1·43	1·34	..	..	..	..
91	26·66	33·33	..	1·40	..	..	..	..	..	..	..
92	27·11	33·88	..	1·44	..	..	..	..	1·42	1·42	..

SYNOPSIS, &c.—*continued.*

Temperature.			Force in Inches of Mercury.								
Fahrenheit.	Reaumur	Centigrade.	Robison, by Experiment.	Dalton, by Experiment.	Ure.		Creighton, by Calculation.	Watt, by Experiment.	Southern.		Taylor, by Experiment.
					By Experiment.	By Calculation.			By Experiment.	By Calculation.	
93°	27°·11	33°·88	..	1·48	..	..	..	..	..	..	..
94	27·55	34·44	..	1·53	..	..	..	..	..	..	..
95	28·00	35·00	..	1·58	1·64	..	..	1·30	..	..	..
96	28·44	35·55	..	1·63	..	..	..	..	..	..	..
97	28·88	36·11	..	1·68	..	..	..	..	..	..	..
98	29·33	36·66	..	1·74	..	..	..	..	..	..	..
99	29·77	37·22	..	1·80	..	..	..	..	..	..	..
100	30·22	37·77	1·60	1·86	1·86	1·92	1·84	..	..	..	..
101	30·66	38·33	..	1·92	..	..	..	..	..	..	..
102	31·11	38·88	..	1·98	..	..	..	..	1·96	1·97	..
103	31·55	39·44	..	2·04	..	..	..	..	..	..	..
104	32·00	40·00	..	2·11	..	..	..	1·75	..	..	..
105	32·44	40·55	..	2·18	2·10	..	..	..	..	..	..
106	32·88	41·11	..	2·25	..	..	..	..	..	..	..
107	33·33	41·66	..	2·32	..	..	..	..	..	..	..
108	33·77	42·22	..	2·39	..	..	..	..	..	..	..
109	34·22	42·77	..	2·46	..	..	..	..	..	..	..
110	34·66	43·33	2·25	2·53	2·45	2·55	2·49	..	..	..	..
111	35·11	43·88	..	2·60	..	..	..	..	..	..	..
112	35·55	44·44	..	2·68	..	..	..	..	2·66	2·68	..
113	36·00	45·00	..	2·76	..	..	..	..	..	..	..
114	36·44	45·55	..	2·84	..	..	..	..	..	..	..
115	36·88	46·11	..	2·92	2·82	..	..	..	..	..	..
116	37·33	46·66	..	3·00	..	..	..	..	..	..	..
117	37·77	47·22	..	3·08	..	..	..	..	..	..	..
118	38·22	48·77	..	3·16	..	..	..	2·68	..	..	..
119	38·66	48·33	..	3·25	..	..	..	..	..	..	..
120	39·11	48·88	3·00	3·33	3·30	3·37	3·32	..	..	..	..
121	39·55	49·44	..	3·42	..	..	..	..	..	..	..
122	40·00	50·00	..	3·50	..	..	..	..	3·58	3·60	..
123	40·44	50·55	..	3·59	..	..	..	..	..	..	..

SYNOPSIS, &c.—*continued.*

Temperature.			Force in Inches of Mercury.								
					Ure.				Southern.		
Fahrenheit.	Reaumur	Centigrade.	Robison, by Experiment.	Dalton, by Experiment.	By Experiment.	By Calculation.	Creighton, by Calculation.	Watt, by Experiment.	By Experiment.	By Calculation.	Taylor, by Experiment.
124°	40°·88	51°·11	..	3·69	..	..	..	..	..	..	..
125	41·33	51·66	..	3·79	3·83	..	..	..	..	..	..
126	41·77	52·22	..	3·89	..	..	..	..	..	..	..
127	42·22	52·77	..	4·00	..	..	..	..	..	..	..
128	42·66	53·33	..	4·11	..	..	..	3·60	..	..	..
129	43·11	53·88	..	4·22	..	..	..	..	..	..	..
130	43·55	54·44	3·95	4·34	4·36	4·42	4·39	..	..	..	..
131	44·00	55·00	..	4·47	..	..	..	..	..	..	..
132	44·44	55·55	..	4·60	..	..	..	..	4·71	4·76	..
133	44·88	56·11	..	4·73	..	..	..	..	..	..	..
134	45·33	56·66	..	4·86	..	..	..	..	..	..	..
135	45·77	57·22	..	5·00	5·07	..	..	4·53	..	..	..
136	46·22	57·77	..	5·14	..	..	..	..	..	..	..
137	46·66	58·33	..	5·29	..	..	..	..	..	..	..
138	47·11	58·88	..	5·44	..	..	..	..	..	..	..
139	47·55	59·44	..	5·59	..	..	..	..	..	..	..
140	48·00	60·00	5·15	5·74	5·77	5·75	5·74	..	..	..	..
141	48·44	60·55	..	5·90	..	..	..	..	..	..	..
142	48·88	61·11	..	6·05	..	..	..	5·46	6·10	6·22	..
143	49·33	61·66	..	6·21	..	..	..	..	..	..	..
144	49·77	62·22	..	6·37	..	..	..	..	..	..	..
145	50·22	62·77	..	6·53	6·60	..	..	..	..	..	..
146	50·66	63·33	..	6·70	..	..	..	..	..	..	..
147	51·11	63·88	..	6·87	..	..	..	..	..	..	..
148	51·55	64·44	..	7·05	..	..	..	6·40	..	..	..
149	52·00	65·00	..	7·23	..	..	..	..	..	..	..
150	52·44	65·55	6·72	7·42	7·53	7·42	7·43	..	..	..	..
151	52·88	66·11	..	7·61	..	..	..	..	..	..	..
152	53·33	66·66	..	7·81	..	..	..	..	7·90	8·03	..
153	53·77	67·22	..	8·01	..	..	..	7·32	..	..	..
154	54·22	67·77	..	8·20	..	..	..	..	..	..	..

SYNOPSIS, *&c.—continued.*

Temperature.			Force in Inches of Mercury.								
Fahrenheit.	Reaumur	Centigrade.	Robison, by Experiment.	Dalton, by Experiment.	Ure. By Experiment.	Ure. By Calculation.	Creighton, by Calculation.	Watt, by Experiment.	Southern. By Experiment.	Southern. By Calculation.	Taylor, by Experiment.
155°	54°·66	68°·33	..	8·40	8·50	..	..	..	..	..	..
156	55·11	68·88	..	8·60	..	..	..	..	..	..	..
157	55·55	69·44	..	8·81	..	..	..	8·25	..	..	..
158	56·00	70·00	..	9·02	..	..	..	..	..	..	..
159	56·44	70·55	..	9·24	..	..	..	..	..	..	..
160	56·88	71·11	8·65	9·46	9·60	9·50	9·52	..	..	..	..
161	57·33	71·66	..	9·68	..	..	..	9·18	..	..	..
162	57·77	72·22	..	9·91	..	..	..	..	10·05	10·25	..
163	58·22	72·77	..	10·15	..	..	..	..	..	..	..
164	58·66	73·33	..	10·41	..	..	..	10·10	..	..	..
165	59·11	73·88	..	10·68	10·80	..	..	..	..	..	..
166	59·55	74·44	..	10·96	..	..	..	..	..	..	..
167	60·00	75·00	..	11·25	..	..	..	11·07	..	..	..
168	60·44	75·55	..	11·54	..	..	..	..	..	..	..
169	60·88	76·11	..	11·83	..	..	..	..	..	..	..
170	61·33	76·66	11·05	12·13	12·05	12·07	12·07	..	..	..	..
171	61·77	72·22	..	12·43	..	..	..	..	..	..	..
172	62·22	77·77	..	12·73	..	..	..	11·95	12·72	12·94	..
173	62·66	78·33	..	13·02	..	..	..	..	..	..	..
174	63·11	78·88	..	13·32	..	..	..	..	..	..	..
175	63·55	79·44	..	13·62	13·55	..	..	12·88	..	..	..
176	64·00	80·00	..	13·92	..	..	..	..	..	..	..
177	64·44	80·55	..	14·22	..	..	..	..	..	..	..
178	64·88	81·11	..	14·52	..	..	..	..	..	..	..
179	65·33	81·66	..	14·83	..	..	..	..	..	..	..
180	65·77	82·22	14·05	15·15	15·16	15·20	15·18	14·73	..	..	..
181	66·22	82·77	..	15·50	..	..	..	..	..	..	..
182	66·66	83·33	..	15·86	..	..	..	..	16·01	16·17	..
183	67·11	83·88	..	16·23	..	..	..	..	..	..	..
184	67·55	84·44	..	16·61	..	..	..	..	..	..	..
185	68·00	85·00	..	17·00	16·90	..	..	16·58	..	..	..

SYNOPSIS, *&c.—continued.*

Temperature.			Force in Inches of Mercury.								
Fahrenheit.	Reaumur	Centigrade.	Robison, by Experiment.	Dalton, by Experiment.	Ure. By Experiment.	Ure. By Calculation.	Creighton, by Calculation.	Watt, by Experiment.	Southern. By Experiment.	Southern. By Calculation.	Taylor, by Experiment.
186°	68°·44	85°·55	..	17·40	..	..	..	..	..	..	..
187	68·88	86·11	..	17·80	..	..	..	17·51	..	..	..
188	69·33	86·66	..	18·20	..	..	..	..	..	..	..
189	69·77	87·22	..	18·60	..	..	..	18·45	..	..	..
190	70·22	87·77	17·85	19·00	19·00	19·00	18·94	..	..	..	..
191	70·66	88·33	..	19·42	..	..	..	19·38	..	..	..
192	71·11	88·88	..	19·86	..	..	..	..	..	20·04	..
193	71·55	89·44	..	20·32	..	..	..	..	..	..	..
194	72·00	90·00	..	20·77	..	..	..	..	..	..	..
195	72·44	90·55	..	21·22	21·10	..	..	..	..	..	..
196	72·88	91·11	..	21·68	..	..	..	..	..	..	..
197	73·33	91·66	..	22·13	..	..	..	..	..	..	..
198	73·77	92·22	..	22·69	..	..	..	..	..	..	..
199	74·22	92·77	..	23·16	..	..	..	..	..	..	..
200	74·66	93·33	22·62	23·64	23·60	23·50	23·44	..	..	..	..
201	75·11	93·88	..	24·12	..	..	..	..	..	..	..
202	75·55	94·44	..	24·61	..	..	..	..	..	24·61	..
203	76·00	95·00	..	25·10	..	..	..	..	..	..	..
204	76·44	95·55	..	25·61	..	..	..	..	..	..	..
205	76·88	96·11	..	26·13	25·90	..	..	..	..	..	..
206	77·33	96·66	..	26·66	..	..	..	..	..	..	..
207	77·77	97·22	..	27·20	..	..	..	..	..	..	..
208	78·22	97·77	..	27·74	..	..	..	..	..	..	..
209	78·66	98·33	..	28·29	..	..	..	..	..	..	..
210	79·11	98·88	28·65	28·84	28·88	28·90	28·81	..	..	..	..
211	79·55	99·44	..	29·41	..	..	..	..	..	..	..
				By Calculation.							
212	80·00	100·00	..	30·00	30·00	30·00	30·00	..	30·00	30·00	..
213	80·44	100·55	..	30·60	..	..	..	30·00	..	..	..
214	80·88	101·11	..	31·21	.	..	..	..	..	..	31·00
215	81·33	101·66	..	31·83	..	..	..	31·00	..	..	..

SYNOPSIS, &c.—*continued.*

Temperature.			Force in Inches of Mercury.								
Fahrenheit.	Reaumur.	Centigrade.	Robison, by Experiment.	Dalton, by Calculation.	Ure. By Experiment.	Ure. By Calculation.	Creighton, by Calculation.	Watt, by Experiment.	Southern. By Experiment.	Southern. By Calculation.	Taylor, by Experiment.
216°	81°·77	102°·22	..	32·46	..	..	..	..	..	..	32·30
217	82·22	102·77	..	33·09	..	..	..	32·00	..	..	33·00
218	82·66	103·33	..	33·72	..	..	..	..	..	..	33·70
219	83·11	103·88	..	34·35	..	..	..	33·00	..	..	34·20
220	83·55	104·44	35·80	34·99	35·54	35·54	35·17	..	..	..	35·00
221	84·00	105·00	..	35·63	..	..	.	..	..	..	35·50
222	84·44	105·55	..	36·25	..	..	..	35·00	..	..	36·20
223	84·88	106·11	..	36·88	..	..	..	..	..	..	37·00
224	85·33	106·66	..	37·53	..	..	..	..	..	..	37·50
225	85·77	107·22	..	38·20	39·11	..	..	37·00	..	..	38·00
226	86·22	107·77	..	38·89	..	..	..	..	..	..	38·80
227	86·66	108·33	..	39·59	..	..	..	..	..	..	39·50
228	87·11	108·88	..	40·30	..	..	..	39·00	..	..	40·20
229	87·55	109·44	..	41·02	..	..	..	..	..	..	40·85
230	88·00	110·00	44·50	41·75	43·10	43·36	42·66	..	..	..	41·55
231	88·44	110·55	..	42·49	..	..	..	41·00	..	..	42·25
232	88·88	111·11	..	43·24	..	..	..	..	..	..	43·00
233	89·33	111·66	..	44·00	..	..	..	..	..	..	43·75
234	89·77	112·22	..	44·78	..	..	..	43·00	..	..	44·60
235	90·22	112·77	..	45·58	47·22	..	..	44·00	..	..	45·50
236	90·66	113·33	..	46·39	..	..	..	..	..	..	46·40
237	91·11	113·88	..	47·20	..	..	..	..	..	..	47·30
238	91·55	114·44	..	48·02	..	..	..	..	..	..	48·20
239	92·00	115·00	..	48·84	..	..	..	..	..	..	49·10
240	92·44	115·55	54·90	49·67	51·70	52·46	51·44	49·00	..	..	50·00
241	92.88	116·11	..	50·50	..	..	..	..	..	..	50·90
242	93·33	116·66	..	51·34	53·60	..	..	..	..	..	51·75
243	93·77	117·22	..	52·18	..	..	..	..	..	..	52·62
244	94·22	117·77	..	53·03	..	..	..	..	..	..	53·50
245	94·66	118·33	..	53·88	56·34	..	..	..	..	..	54·40
246	95·11	118·88	..	54·68	..	..	..	..	..	..	55·30

SYNOPSIS, *&c.—continued.*

Temperature.			Force in Inches of Mercury.								
Fahrenheit.	Reaumur	Centigrade.	Robison, by Experiment.	Dalton, by Calculation.	Ure.		Creighton, by Calculation.	Watt, by Experiment.	Southern.		Taylor, by Experiment.
					By Experiment.	By Calculation.			By Experiment.	By Calculation.	
247°	95°·55	119°·44	..	55·64	..	..	..	54·00	..	..	56·25
248	96·00	120·00	..	56·42	..	..	..	..	..	..	57·20
249	96·44	120·55	..	57·31	..	..	..	..	..	..	58·20
250	96·88	121·11	66·80	58·21	61·90	62·95	61·68	..	60·00	60·11	59·12
251	97·33	121·66	..	59·12	..	..	..	..	..	..	60·10
252	97·77	122·22	..	60·05	..	..	..	..	..	..	61·12
253	98·22	122·77	..	61·00	..	..	..	..	..	..	62·15
254	98·66	123·33	..	61·92	..	..	..	..	..	..	63·20
255	99·11	123·88	..	62·85	67·25	..	..	62·00	..	..	64·40
256	99·55	124·44	..	63·76	..	..	..	..	..	..	65·50
257	100·00	125·00	..	64·82	..	..	..	64·00	..	..	66·60
258	100·44	125·55	..	65·78	..	..	..	..	..	..	67·75
259	100·88	126·11	..	66·75	..	..	..	66·00	..	..	69·00
260	101·33	126·66	80·30	67·73	72·30	74·91	73·57	..	..	..	70·12
261	101·77	127·22	..	68·72	..	..	..	68·00	..	..	71·25
262	102·22	127·77	..	69·72	..	..	..	..	..	..	72·45
263	102·66	128·33	..	70·73	..	..	..	..	..	..	73·52
264	103·11	128·88	..	71·74	..	..	..	..	..	..	74·80
265	103·55	129·44	..	72·76	78·04	..	..	..	..	..	76·00
266	104·00	130·00	..	73·77	..	..	..	..	..	..	77·25
267	104·44	130·55	..	74·79	81·90	..	..	..	..	..	78·50
268	104·88	131·11	..	75·80	..	..	..	76·00	..	..	79·80
269	105·33	131·66	..	76·82	84·90	..	..	..	..	..	81·14
270	105·77	132·22	94·10	77·85	86 30	88·39	87·31	..	..	..	82·50
271	106·22	132·77	..	78·89	..	..	..	80·00	..	..	83·90
272	106·66	133·33	..	79·94	..	..	..	..	..	..	85 45
273	107·11	133·88	..	80·98	..	..	..	..	..	..	86·95
274	107·55	134·44	..	82·10	..	..	..	..	..	..	88·50
275	108·00	135·00	..	83·13	93·48	..	..	..	..	..	90·00
276	108·44	135·55	..	84·35	..	..	..	..	..	..	91·55
277	108·88	136·11	..	85·47	..	..	..	..	..	..	93·15

SYNOPSIS, *&c.—continued.*

Temperature.			Force in Inches of Mercury.								
Fahrenheit.	Reaumur	Centigrade.	Robison, by Experiment.	Dalton, by Calculation.	Ure. By Experiment.	Ure. By Calculation.	Creighton, by Calculation.	Watt, by Experiment.	Southern. By Experiment.	Southern. By Calculation.	Taylor, by Experiment.
278°	109°·33	136°·66	..	86·50	..	..	..	..	..	..	94·70
279	109·77	137·22	..	87·63	..	..	..	..	..	..	96·26
280	110·22	137·77	105·9	88·75	101·90	103·41	103·13	..	..	..	97·75
281	110·66	138·33	..	89·87	..	..	..	..	..	..	99·25
282	111·11	138·88	..	90·99	..	..	..	..	..	..	100·70
283	111·55	139·44	..	92·11	..	..	..	..	..	..	102·20
284	112·00	140·00	..	93·23	..	..	..	..	..	..	103·80
285	112·44	140·55	..	94·35	112·00	..	..	..	..	..	105·60
286	112·88	141·11	..	95·48	..	..	..	..	..	..	107·30
287	113·33	141·66	..	96·64	..	..	..	..	.	..	109·00
288	113·77	142·22	..	97·80	..	..	..	..	..	..	110·80
289	114·22	142·77	..	98·96	118·20	..	..	..	..	..	112·65
290	114·66	143·33	..	100·12	120·15	119·95	121·27	..	..	..	114·50
291	115·11	143·88	..	101·28	..	..	..	..	..	..	116·40
292	115·55	144·44	..	102·45	..	..	..	..	..	..	118·30
293	116·00	145·00	..	103·03	..	..	..	..	120·00	119·17	120·25
294	116·44	145·55	..	104·80	126·70	..	..	..	..	..	122·20
295	116·88	146·11	..	105·97	129·00	..	..	..	..	..	124·15
296	117·33	146·66	..	107·14	..	..	..	..	..	..	126·05
297	117·77	147·22	..	108·31	..	..	..	..	..	..	128·00
298	118·22	147·77	..	109·48	..	..	..	..	..	..	129·80
299	118·66	148·33	..	110·64	..	..	..	..	..	..	131·62
300	119·11	148·88	..	111·81	139·70	137·94	142·01	..	..	..	133·75
301	119·55	149·44	..	112·98	..	..	..	..	..	..	135·60
302	120·00	150·00	..	114·15	144·30	..	..	..	..	..	137·55
303	120·44	150·55	..	115·32	..	..	..	..	..	..	139·75
304	120·88	151·11	..	116·50	..	..	..	..	..	..	141·90
305	121·33	151·66	..	117·68	150·56	..	..	..	..	..	144·05
306	121·77	152·22	..	114·86	..	..	..	..	..	..	146·15
307	122·22	152·77	..	120·03	..	..	..	..	..	..	148·30
308	122·66	152·33	..	121·20	157·70	..	..	..	..	..	150·65

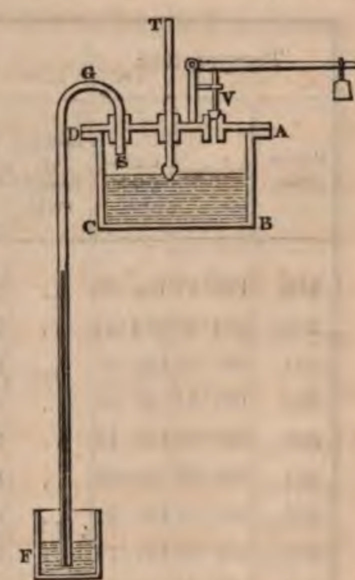
SYNOPSIS, *&c.—continued.*

Temperature.			Force in Inches of Mercury.								
Fahrenheit.	Reaumur	Centigrade.	Robison, by Experiment.	Dalton, by Calculation.	Ure. By Experiment.	Ure. By Calculation.	Creighton, by Calculation.	Watt, by Experiment.	Southern. By Experiment.	Southern. By Calculation.	Taylor, by Experiment.
309°	123°·11	153°·88	..	122·37	..	..	..	..	..	..	157·70
310	123·55	154·44	..	123·58	161·30	157·25	165·61	..	..	..	155·00
311	124·00	155·00	..	124·69	..	..	..	..	..	..	157·20
312	124·44	155·55	..	125·85	166·00	..	..	..	..	..	459·45
313	124·88	156·11	..	127·00	..	..	..	..	..	..	161·75
314	125·33	156·66	..	128·15	..	..	..	..	..	..	164·20
315	125·77	157·22	..	129·29	..	..	..	..	..	..	166·70
316	126·22	157·77	..	130·43	..	..	..	..	..	..	169.15
317	126·66	158·33	..	131·57	..	..	..	..	..	..	171·70
318	127·11	158·88	..	132·72	..	..	..	..	..	..	174·30
319	127·55	159·44	..	133·86	..	..	..	..	..	..	176·80
320	128·00	160·00	..	135·00	..	177·70	..	..	..	..	179·40
321	128·44	160·55	..	136·14	..	..	..	..	..	..	..
322	128·88	161·11	..	137·28	..	..	..	..	..	..	..
323	129·33	161·66	..	138·42	..	..	..	..	..	..	..
324	129·77	162·22	..	139·56	..	..	..	..	..	..	..
325	130·22	162·77	..	140·70	..	..	..	..	..	..	..
343·6	138·49	173·11	..	..	..	..	..	..	240·00	239·28	..

Since differences must be observed in the numbers, which, in the preceding tables, represent the force of steam, it becomes necessary briefly to detail the mode of conducting the respective experiments, in order that it may be seen from what circumstances such differences are likely to have arisen.

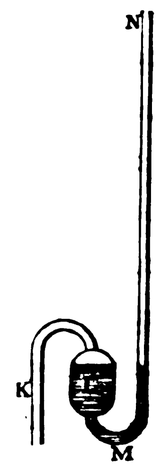
The experiments of Professor Robison were performed with a small copper digester, A B C D, furnished with a glass syphon, S G E, a thermometer, T, and a safety-valve, V. The digester was filled

with distilled water, freed from air by boiling; and a lamp was placed beneath it, which caused the water within to boil, and the steam to issue copiously both from the valve and syphon. After the steam had been allowed to escape for some time, the valve was loaded; the lower end of the syphon immersed in a broad vessel of mercury; and the lamp removed from beneath the digester. A gradual condensation of the steam ensued; and the mercury, without sensibly sinking in the vessel F, rose in the syphon until it had attained the height of 29·7 inches, which proved that a very complete condensation had been effected. To ascertain with greater certainty whether such were the case, the digester was surrounded by pounded ice of the temperature 32°, but no sensible change took place in the height of the mercury; the pounded ice was therefore removed, and the water heated very slowly. One observer was stationed at the thermometer, with instructions to call out as the mercurial column reached the divisions 42, 47, 52, 57, and so on progressively; and another observer noted the corresponding descents of the mercury in the syphon by a scale of inches, affixed to a post, beginning at 29·84 inches from the surface of the mercury. During the experiments the weather was clear and frosty, the barometer indicating 29·84 inches, and the thermometer in the digester 42°. These experiments, being easily made, were several times repeated, and the mean results set down; but it should be observed, that as the descent of the mercury was very rapid, it was found extremely



difficult to note it for every fifth degree: every tenth degree was therefore judged sufficient to establish the law of variation.

Having by these means obtained the elasticity of vapour between the temperatures 32° and 212°, the professor next proceeded to experiment on the higher temperatures. He removed the syphon S G E from the third hole of the lid of the digester, and substituted the syphon K M N, which was about six feet two inches long. The short leg, K, was inserted into the digester, and the cistern, L, between the two legs of the syphon, was filled with mercury. The longer leg was furnished with a scale of inches. After the steam had been allowed to escape for some time through the valve, it was, as before, confined



by a weight, such as it was known the digester could support, without allowing the steam to force the mercury out of the tube M N. The mercury in the thermometer immediately began to ascend, as also did that in the longer leg of the syphon, and their correspondent stations are marked from 220° to 280° inclusively in the foregoing synopsis of results.

In reference to the preceding experiments it may be necessary to observe, that four or five numbers at the beginning of Professor Robison's table of elasticities are not so accurate as the others, because the mercury passed rather rapidly through those points. The progress was afterwards extremely regular; but as the professor has assumed the force of vapour of 32° to be nothing, he is essentially wrong in the low degrees of temperature; and the errors are still farther increased by the vacant part of the barometer tube not being of equal temperature with the digester. In the high degrees of the scale, or above 212°, he has represented the force too high,

owing, probably, to a quantity of air, disengaged from the water by heat, mixing with and increasing the elasticity of the steam.

To obviate these sources of error, Mr. Dalton conducted a series of experiments by means of a much more simple and satisfactory contrivance.* He procured a perfectly dry barometer tube of the usual size; and, having introduced some mercury, which had been previously freed from air by boiling, marked the place where it became stationary. Then, dividing the space occupied by the mercurial column into inches and tenths, he poured out the mercury, and introduced some water to moisten the inside of the tube. On reversing the operation, that is, pouring out the water, and reintroducing the mercury, the water which adhered to the sides of the tube rose to the top of the mercurial column, where it formed a stratum from one-eighth to one-tenth of an inch in depth. The air was carefully excluded. Having thus satisfied himself as to the probable accuracy of the results to be obtained, he took an open cylindrical glass tube, two inches diameter and fourteen inches long, in each end of which he fixed a cork. The corks were perforated in the middle, to admit the upper or vacant part of the barometer tube. The upper cork was fixed two or three inches below the top of the tube, and a small portion of it was cut away to allow water to be poured into the space between it and the lower cork. By this means, the upper or vacant part of the barometer tube was exposed to the several degrees of temperature from 32° to 155° inclusively; and the effect of heat, in the production of vapour within, was observed by the depression of the mercurial column. In experimenting on the higher temperatures, Mr. Dalton used a nearly

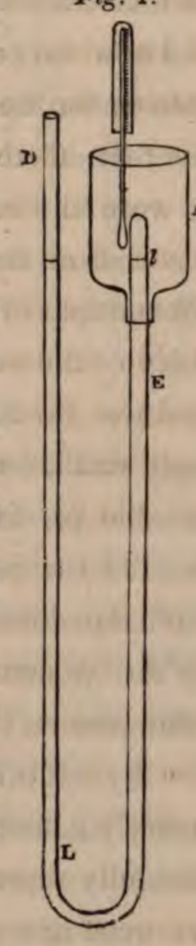
* Manchester Memoirs, vol. v.

similar apparatus, made of tin, with a syphon barometer, and thus obtained the remaining results up to 212 degrees.

The results of these experiments from 32° to 212° inclusively we consider to be as accurate as their nature will admit; and are induced to place greater confidence in them, from their agreeing very closely with the results of experiments made by Dr. Ure and Mr. Southern.

Dr. Ure has thus detailed his experiments :* "Fig. 1 represents the construction employed for temperatures under, and a little above, the boiling points. Figs. 2 and 3 are used for higher temperatures; and the last is the most convenient. One simple principle pervades the whole train of experiments, which is, that the progressive increase of elastic force developed by heat from the liquid, incumbent on the mercury at *l l′ l″*, is measured by the length of column which must be *added* over L, the primitive level below, in order to restore the quicksilver to its primitive level above, at *l*. These two stations, or points of departure, are nicely defined by a ring of fine platina wire twisted firmly around the tube.

Fig. 1.



"At the commencement of the experiment, after the liquid, well freed from air, has been let up, the quicksilver is made a tangent to the edge of the upper ring, by cautiously pouring mercury in a slender stream into the open leg of the syphon D. The level ring below is then carefully adjusted.

* Trans. Royal Society, 1818.

"From the mode of conducting these experiments, there remained always a quantity of liquid in contact with the vapour, a circumstance essential to accuracy in this research.

"Suppose the temperature of the water or the oil in A to be 32° F., as denoted by a delicate thermometer, or by the liquefaction of ice; communicate heat to the cylinder A by means of two Argand flames playing gently on its shoulder at each side. When the thermometer indicates 42°, modify the flames, or remove them, so as to maintain an uniform temperature for a few minutes. A film, or line of light, will now be perceived between the mercury and the ring at *l*, as is seen under the vernier of a mountain barometer when it is raised a few feet off the ground. Were the tube at *l* and L of equal area, or were the relation of the areas experimentally determined, then the rise of the quicksilver above L would be one half, or a known submultiple of the total depression, equivalent to the additional elasticity of the vapour at 42° above that at 32°. Since the depressions, however, for 30 or 40 degrees in this part of the scale are exceedingly small, one half of the quantity can scarcely be ascertained with suitable precision, even after taking the above precautions; and, besides, the other sources of error, or, at least, embarrassment, from the inequalities of the tube, and from the lengthening space occupied by the vapour, as the temperature ascends, render this method of reduction very ineligible.

"By the other plan we avoid all these evils. For whatever additional elasticity we communicate to the vapour above *l*, it will be faithfully represented and measured, by the mercurial column which we must add over L, in order to overcome it, and restore the quick-

silver under l to its zero or initial level, when the platina ring becomes once more a tangent to the mercury.*

Fig. 2.

"At E a piece of cork is fixed, between the parallel legs of the syphon, to sustain it, and to serve as a point by which the whole is steadily suspended.

"For temperatures above the boiling point, the part of the syphon under E is evidently superfluous, merely containing in its two legs a useless weight of equipoise mercury. Accordingly, for high heats, the apparatus figs. 2 or 3 is employed, and the same method of procedure is adopted. The aperture at O, fig. 3, admits the bulb of the thermometer, which rests as usual on l''. The recurved part of the tube is filled with mercury, and then a little liquid is passed through it to the sealed end. Heat is now applied by an Argand flame to the bottom of C, which is filled with oil, or water; and the temperature is kept steadily at 212° for some minutes. Then a few drops of quicksilver may require to be added to D'' till L'' and l'' be in the same horizontal plane. The further conduct of the experiment differs in no respect from what has been already described. The liquid in C is progressively heated, and at each stage mercury is progressively added over L'' to restore the initial level, or volume at

* Rings of other metals will not suit; for, their expansions being much greater than that of glass, they become loose with the elevation of temperature.

l'', by equipoising the progressive elasticity. The column above L″ being measured, represents the succession of elastic forces. When this column is wished to extend very high, the vertical tube requires to be placed for support in the groove of a long wooden prism.

Fig. 3.

"The height of the column in some of the experiments being nearly 12 feet, it became necessary to employ a ladder to reach its top. It was found to be convenient in this case, after observing that the column of vapour had attained its primitive magnitude, to note down the temperature with the altitude of the column; then immediately to pour in a measured quantity of mercury nearly equal to three vertical inches, and to wait till the slow progress of the heating again brought the vapour in equilibrio with this new pressure, which at first had pushed the mercury within the platina ring at l''. When the lower surface of the mercury was again a tangent to this ring, the temperature and altitude were both instantly observed. This mode of conducting the process will account for the experimental temperatures being very often odd and fractional numbers. They are therefore presented to the public as they were recorded on the instant.

"The thermometers were constructed by Creighton with his well-known nicety, and the divisions were read off with a lens, so that $\frac{1}{10}$ of a degree could be distinguished. After bestowing the utmost

pains in repeating the experiments during a period of nearly two months, it was found that the only way of removing the little discrepancies which crept in between contiguous measures, was to adopt the astronomical plan of multiplying observations and deducing truth from the mean. It is essential to heat with extreme slowness and circumspection the vessels A B C. One repetition of the experiment occupies, on an average, seven hours."

A surprising accordance will be perceived in the numbers between 32° and 212°, given by Dr. Ure and by Mr. Dalton, though the experiments were performed with different apparatus. This accordance is highly creditable to the talents of both these distinguished experimenters. In the high degrees we suspect Dr. Ure's numbers to be erroneous. This suspicion, it should be stated, rests solely upon a careful comparison of his results with those obtained by Mr. Southern and Mr. Philip Taylor.

The experiments of Watt and Southern were made at different periods, and with but little reference to each other; they are, however, so intimately connected, that we find the necessity of blending them together. Comparatively speaking, the experiments were made at a very early date; those of Mr. Watt prior to any with which we are acquainted, and those of Mr. Southern subsequent only to the experiments of Professor Robison. Mr. Watt conducted his experiments with a tin pan, 5 inches diameter, and 4 inches deep, having an inverted barometer tube, 3 feet long, firmly fixed into a conical socket at the bottom, through which it passes. At one extremity of this tube was a bulb, an inch and a half in diameter, the capacity of which was nearly equal to the capacity of the tube. The bulb was filled with water, and the stem with mercury, and

the lower end of the latter was immersed in a cistern of mercury. These were so perfectly freed from air, that the column of mercury in the tube was 34 inches high: when it was violently shaken, the mercurial column suddenly descended, and settled at 28·75 inches. Upon being inclined, a speck of air still remained; but when it was compressed by a pillar of mercury 27 inches high, this speck was not larger than a pin's head. When the tube was perpendicular, the mercury stood at 28·75 inches; and the column of water above it was about 6½ inches, which is equal to half an inch of mercury. As the whole was 29·25 inches when the stationary barometer stood at 29·4, the difference, or pillar supported by the elasticity of the steam, was equal to 0·15 inch. The water in the pan was heated slowly by a lamp, and was stirred continually with a feather to distribute the heat equably throughout. By these means experiments were made from 55° to 196°·5 of temperature.

To determine the higher degrees of elasticity, Mr. Watt introduced a tube, 55 inches long, through a hole in the lid of a digester, and within the digester it terminated in a cistern of mercury. A thermometer was applied, as in the experiments of Professor Robison, and the digester was half filled with water, and heated by a lamp. This caused the air in the upper part of the digester to expand, and although a considerable quantity was allowed to escape, and the water heated to ebullition,

still some remained, for the mercury stood at $213\frac{1}{2}^{\circ}$. The necessary deductions being made, the synopsis exhibits the elasticities from 213° to 271° inclusively. Dissatified with these experiments, Mr. Watt, in 1796, requested Mr. Southern to repeat them. The particulars are contained in a letter addressed to Mr. Watt,* of which we shall insert those parts which strictly relate to our present purpose.

"Mr. Southern premises that the thermometers employed in all the experiments were made and graduated with the greatest care, the tubes having been accurately measured as to the proportional capacity of their different parts, the boiling point of each ascertained, according to the rules prescribed by a committee of the Royal Society in 1777, (viz. the bulbs and tubes being in steam when the barometer stood at 29·8 inches, this degree of temperature being called 212°,) and in all cases the bulb and the tube, as high as the mercury ascended in it, were kept in the steam or the water whose temperature was to be noted. This latter circumstance was effected in the case of steam, by sliding the tube of the thermometer through a stuffing-box, or collar, made tight, till the mercury could be just seen above it. The tube had known marks on it, from which measurements were taken to the mercury, and thence the temperature known.

"The quantity of steam was known by allowing it to flow into a cylinder (enclosed in steam) whose diameter was about 3·16 inches; and it was driven out by the motion of a piston, which had 18 inches stroke regulated by the rotation of a crank. The solid contents of the piston rod, which was 0·86 inch diameter, diminished the contents of

* Professor Robison's Mechanical Philosophy.

the cylinder, leaving the quantity discharged each stroke by the motion of the piston, very nearly 130·7 cubic inches; but as the piston did not rise high enough to touch the top that closed the cylinder, and there was also unavoidably a space between the valve and the cylinder, these spaces together were computed to be equal to 1·7 cubic inch. Of course, had the elasticity of the steam been just equal to that of the atmosphere, no addition to the 130·7 cubic inches would need to be made; but as in the three successive experiments it was about $\frac{1}{3}$, $\frac{5}{3}$, and $\frac{9}{3}$ greater, these proportions of the spaces would escape when the valve was open that allowed the discharge of the steam tc be made into the atmosphere, and must therefore be added respectively to the contents discharged by the motion of the piston.

"These additional quantities are $1·7 \times \frac{1}{3} = 57$; $1·7 \times \frac{5}{3} = 2·83$; and $1·7 \times \frac{9}{3} = 5·1$; which, added to 130·7, gives 131·27 in the first experiment, 133·53 in the second, and 135·8 in the third, for the quantity of steam discharged at each stroke of the piston; and therefore the number of strokes which would discharge one cubic foot in each of the three experiments, would be 13·164, 12·941, and 12·724 respectively.

"The steam was conducted from the cylinder, after passing the valve, by means of an iron pipe attached to a small copper one, having its end bent down, and immersed a short depth into a cistern of water. The cistern was made of fir wood, and painted inside and outside with white paint; was about 30 inches square, and 26 inches deep; and the quantity of water in it was ascertained by weighing, as was also the accession to it by the condensed steam.

" The elasticity of the steam was ascertained by measuring an actual column of mercury which it supported; and the number of strokes was ascertained by a machine called a counter.

" The following table contains the principal facts of these experiments.

No. of Experiment.	Duration of the Experiment, in minutes.	Whole No. of Strokes.	No. of Strokes per minute.	Weight of Water in Cistern at beginning in lbs.	Temperature of ditto.	Weight of Water gained by condensed Steam, in lbs.	Temperature of Water in Cistern at the end.	Temperature gained.	Elasticity of Steam in Boiler in Inches of Mercury.	Temperature of ditto.
1	2	3	4	5	6	7	8	9	10	11
1	$121\frac{3}{4}$	5154	42·3	$721\frac{3}{4}$	$45\frac{2}{3}^{\circ}$	20·25	76°	$30\frac{1}{3}^{\circ}$	40	229°
2	$51\frac{1}{2}$	2434	$41\frac{1}{4}$	722	48	20·00	$80\frac{1}{4}$	$32\frac{1}{4}$	80	270
3	$38\frac{1}{4}$	1599	41·8	722	48	19·45	$79\frac{3}{4}$	$31\frac{3}{4}$	120	295

" If the whole number of strokes in each experiment be divided by the number found as above, that were required to discharge one cubic foot of steam, the whole number of cubic feet of steam discharged in each experiment will be given, *viz.* $5154 \div 13{\cdot}164 = 391{\cdot}53$; $2434 \div 12{\cdot}941 = 188{\cdot}09$; and $1599 \div 12{\cdot}724 = 125{\cdot}66$; the quantity of steam formed and discharged in the first, second, and third experiments respectively in cubic feet.

" If the weight of water gained by the condensation of steam in each experiment be multiplied by 27·65, the number of cubic inches of water in a pound weight, and divided by the number of cubic feet of steam which were condensed, the quotient will give the portion of water, in cubic inches, required by each cubic foot of steam for its formation; and hence also the comparative density.

Thus $$20{\cdot}25 \times 27{\cdot}65 \div 391{\cdot}53 = 1{\cdot}430$$
$$20{\cdot}00 \times 27{\cdot}65 \div 188{\cdot}09 = 2{\cdot}940$$
$$19{\cdot}45 \times 27{\cdot}65 \div 125{\cdot}66 = 4{\cdot}279$$

inches of water to form each cubic foot of steam; and these numbers are proportional to 40·00, 82·24, and 119·70, the relative densities, while the elasticities were as 40, 80, and 120 respectively.

"These results appear to support the conclusion, that *the density of steam is nearly, if not accurately, proportional to its elasticity*; at least this may be affirmed of it within the limits of these experiments." * * * * *

Besides the experiments detailed above, in which the temperature of steam formed under *high pressures* was observed, others had been made some years before; and as they were performed with the greatest circumspection, both the manner of making them and their results may be here described.

The instrument used to determine the elasticities at high temperatures was a Papin's digester, similar to that of Professor Robison; but a metallic tube was adapted to it to contain the thermometer, or rather as much of it as contained mercury, in the manner already mentioned; and instead of a valve for measuring the elasticity of the contained steam, a nicely bored cylinder was applied, with a piston fitting it, so as to have very little friction. To the rod of this was applied a lever, constructed to work on edges, by which the resistance against the elastic force of the steam could be accurately determined; and to be sure that no inaccuracy had crept into the calculation, by which this resistance through the medium of the lever was ascertained, an actual column of mercury of 30 inches high was substituted, and the

correspondence was found to be within the one hundredth part of an inch.

The observations at each of the points of pressure noted were continued some minutes, the temperature at each being alternately raised and lowered, so as to make the pressure of the steam on the under side of the piston alternately too much and too little for the weight with which it was loaded; and thence a mean temperature was adopted, the extremes of which did not deviate more than half a degree. The load on the piston, together with its own weight, was calculated to be successively equal to 1, 2, 4, and 8 atmospheres of 29·8 inches of mercury each; and the temperature of the steam was varied, till that of each point was determined. The results were:

Atmospheres.	Pressure in Inches of Mercury.	Temperatures.
1	29·8	212°
2	59·6	250·3
4	119·2	293·4
8	238·4	343·6

The experiments for ascertaining the temperature of steam below the atmospheric pressure, or about 212°, were made with an apparatus similar to that employed by Mr. Watt: and Mr. Southern met with the same incidents, such as the production of a bubble of air when the tube was inclined to refill the ball; and also the extraordinary suspension of a column of mercury of 35 inches vertical height, and of 7 inches of water above that, although the counterpoise

was only that of the atmosphere, then under 30 inches. He also found that the tube required a considerable degree of shaking, to make the column subside, and leave a space in the ball.

The results in the table below were deduced from the observations, by adding to the height of the column of mercury in the tube that of the water above it, or rather of an equivalent column of mercury, and subtracting their sum from the height of the common barometer at the time.

Temperature.	Elasticity.			
	1st Set. Inches.	2d Set. Inches.	3d Set. Inches.	Mean. Inches.
52°	0·0	0·42	0·40	0·41
62	0·53	0·52	0·52	0·52
72	0·73	0·73	0·73	0·73
82	1·03	1·02	1·02	1·02
92	1·42	1·41	1·42	1·42
102	1·98	1·92	1·95	1·95
112	2·67	2·63	2·66	2·65
122	3·58	3·54	3·58	3·57
132	4·68	4·65	4·72	4·68
142	6·05	6·00	6·14	6·06
152	7·86	7·80	7·89	7·85
162	9·98	9·96	10·04	9·99
172	12·54	12·72	12·67	12·64
182	16·01	15·84	15·88	15·91

As the temperature 212° is now generally considered to be the boiling point of water, when the mercury is at 30, and not 29·8 inches, the alterations necessary to suit that pressure have been made in the synopsis.

From the great care with which these experiments were conducted, and the agreement of the results, we regret that they were not continued through the successive degrees of temperature, as we might then have regarded them as the true standard of elasticities. They are however of importance, as they tend to confirm our opinion, that the table by Mr. Dalton between 32° and 212°, and that by Mr. Philip Taylor in the higher ranges, are sufficiently correct for practical purposes.

The experiments of Mr. Philip Taylor were made with a strong boiler, furnished with the required thermometer and barometer. During the ascent of the mercurial column of the thermometer, and the corresponding descent of the barometer, the indications of temperature and elasticity were accurately noted; and when the steam had attained 320°, it was allowed gradually to subside, and the states of temperature and elasticity again ascertained. Thus a mean result was obtained, which is essential to great accuracy, for between the alternate ascents and descents of the mercurial columns there is some variation. From the manner in which Mr. Taylor constructed his table, it is not improbable that the synopsis may exhibit a few errors in the decimal parts of the inch, we therefore introduce it in its original form.

The synopsis being too voluminous to be at all times at command for the purposes of practical reference, we shall present formulæ

for calculating the elasticity of steam at any given temperature, commencing with that by Mr. Dalton.

On examining the results of his experiments between 32° and 212°, Mr. Dalton observed something like a geometrical progression, with a ratio, however, gradually diminishing:—Thus

			Inch.	Ratios.
the force at	32°	=	·200	
	122	=	3·500	17·50
	212	=	30·000	8·57

and if divided, according to observation

the force at	32°	=	·200	
	77	=	·910	4·550
	122	=	3·500	3·846
	167	=	11·250	3·214
	212	=	30·000	2·666

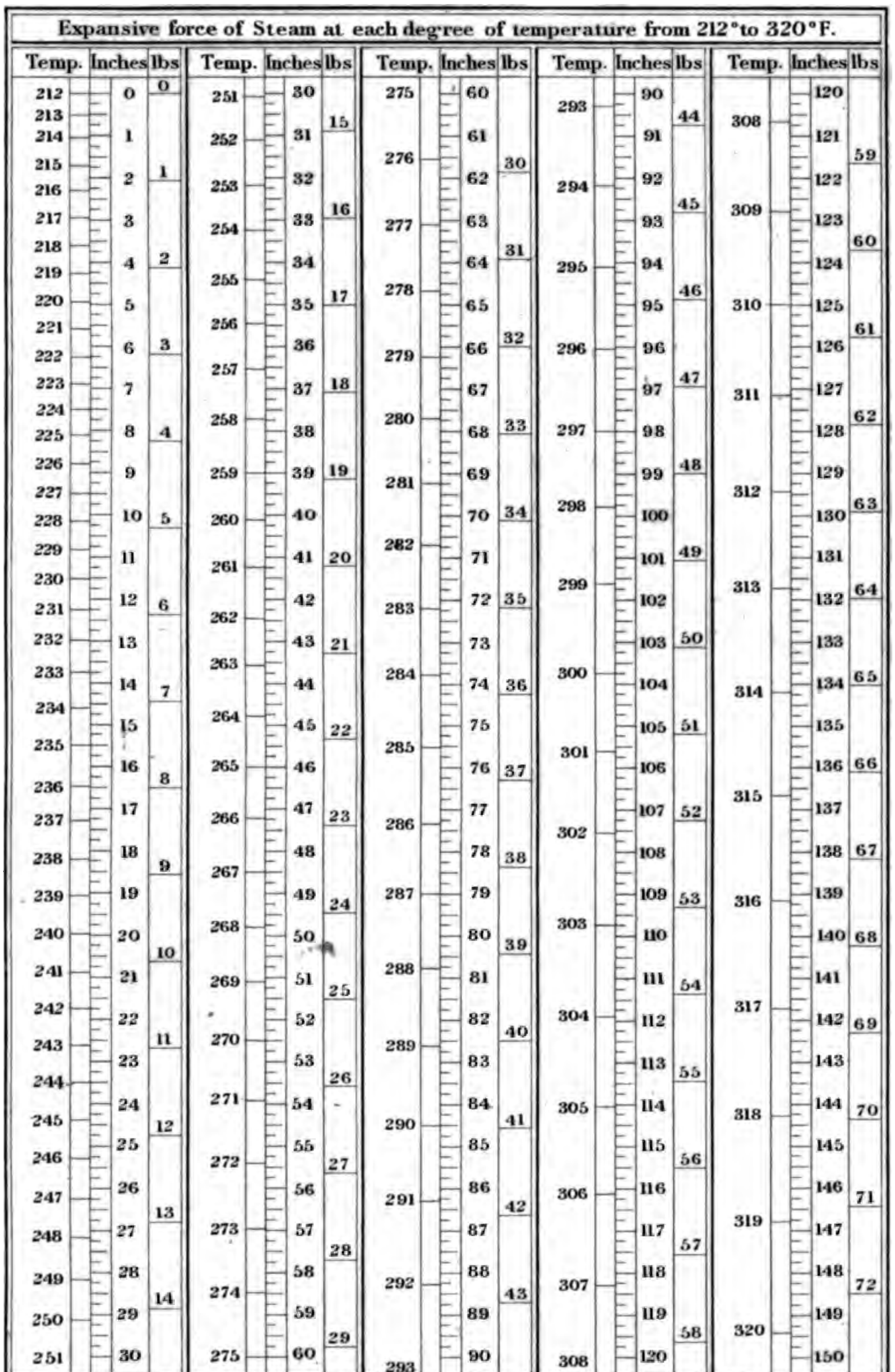
and if again divided:

the force at	32°	=	·200	
	54½	=	·435	2·17
	77	=	·910	2·09
	99½	=	1·820	2·00
	122	=	3·550	1·92
	144½	=	6·450	1·84
	167	=	11·250	1·75
	189½	=	18·800	1·67
	212	=	30·000	1·59

and by another division we obtain the ratio for every addition of eleven degrees and a quarter to the temperature:

the force at	32°	=	·200	
	43¼	=	·297	1·485
	54½	=	·435	1·465
	65¾	=	·630	1·44
	77	=	·910	1·43
	88¼	=	1·290	1·41
	99½	=	1·820	1·40

Mr. PHILIP TAYLOR'S TABLE OF ELASTICITIES.



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	Inch.	Ratios.
$99\frac{1}{2}$ =	1·820	
		1·40
$110\frac{3}{4}$ =	2·540	
		1·38
122 =	3·500	
		1·36
$133\frac{1}{4}$ =	4·760	
		1·35
$144\frac{1}{2}$ =	6·450	
		1·33
$155\frac{3}{4}$ =	8·550	
		1·32
167 =	11·250	
		1·30
$178\frac{1}{4}$ =	14·600	
		1·29
$189\frac{1}{2}$ =	18·800	
		1·27
$200\frac{3}{4}$ =	24·000	
		1·25
212 =	30·000	

By this mode of estimation Mr. Dalton concluded that, without the aid of experiment, he might, with tolerable accuracy, extend the table several degrees below 32° and beyond 212°. Thus assuming the ratio for each interval of $11\frac{1}{4}$° above 212° to be 1·235, 1·220, 1·205, 1·190, 1·175, 1·160, 1·145, 1·130, &c. he has extended the table through many similar intervals, and determined the intermediate degrees, as exhibited in the synopsis, by interpolation. But unfortunately the results, though for many years regarded as the standard, differ very materially from those obtained by experiment.

In this exhibition of useful formulæ, our attention is necessarily turned to M. Biot, who, in his "Traité de Physique," has happily brought many of the vague disquisitions of physical science within the correcting influence of analysis. He has deduced a general formula from Mr. Dalton's experiments, for calculating the force of steam at any given temperature; and respecting this formula, we may, in the first place, observe, that M. Biot represents the decrease of the logarithms of the elastic forces by a series of terms of the form $a\,n + b\,n^2 + c\,n^3$; $a\,b\,c$ being constant coefficients.

$$\text{Thus log. } F_n = \text{log. } 30 + a\,n + b\,n^2 + c\,n^3$$

It is unnecessary, he continues, to employ powers of n higher than the cube, because their coefficients would be insensible, as the calculation will show. To determine the coefficients a b c, he makes use of the elastic forces observed at the temperatures on the centigrade scale of 100°, 75°, 50°, and 25°; whence result these conditions:

$$\begin{array}{ll} & \text{Inches.} \\ n = 0 & F \ = 30{\cdot}00 \\ n = 25 & F_{25} = 11{\cdot}25 \\ n = 50 & F_{50} = \ 3{\cdot}50 \\ n = 75 & F_{75} = \ \ {\cdot}91 \end{array}$$

Substituting these conditions in the above general formula, and bearing in mind that the logarithm of a fraction is equal to the logarithm of the numerator, minus the logarithm of the denominator, we shall have the three following equations of conditions:

$$\begin{aligned} -\ 0{\cdot}4259687 &= 25\,a + 625\ \ b + 15625\ \ c \\ -\ 0{\cdot}9330519 &= 50\,a + 2500\,b + 125000\,c \\ -\ 1{\cdot}5180799 &= 75\,a + 5625\,b + 421875\,c \end{aligned}$$

Doubling the first, and subtracting it from the second, a disappears; trebling it, and subtracting it from the third, a also disappears. Then dividing each of the two resulting equations by the coefficient of b, we have

$$\begin{aligned} -\ 0{\cdot}00006489160 &= b + 75\,c \\ -\ 0{\cdot}00006404635 &= b + 100\,c \end{aligned}$$

Subtracting one of these from the other, b will disappear; and dividing it by the coefficient of c, we shall have c. Next, by substituting the value of c in one of these equations, we get b. Lastly, putting b and c in one of the two first equations, we have a. Thus we shall find

$$\begin{aligned} a &= -\ 0{\cdot}01537419550 \\ b &= -\ 0{\cdot}00006742735 \\ c &= +\ 0{\cdot}00000003381 \end{aligned}$$

Whence the whole formula $\log. F_n = \log. 30 + an + bn^2 + cn^3$ is completely determined, and may serve for calculating F_n, relative to any proposed value of n.

If we make, for example, $n = 100°$, we shall have the elastic force at 100° below the boiling point, or at the temperature of melting ice. We thus obtain

$$\text{Log. } F_n = 1\cdot4771213 - 2\cdot1778831 = -0\cdot7007618$$

Or employing negative indices in order to make use of the ordinary logarithmic tables,

$$\text{Log. } F_n = \bar{1}\cdot2992382 \text{ whence } F_n = 0\cdot19917 \text{ inches,}$$

Observation gives 0·200.

The error is obviously insensible ; and we may adopt, says M. Biot, our formula as representing the experiments of Mr. Dalton. To introduce the Fahrenheit degrees into the formula, calling them f, and counting from 212°, we have $\frac{5}{9} f = n$; and substituting the value of n in the preceding formula, we obtain

$$\begin{aligned} a &= -\ 0\cdot00854121972 \\ b &= -\ 0\cdot00002081091 \\ c &= +\ 0\cdot00000000580, \end{aligned}$$

whence $\log. F_f = 1\cdot4771213 + af + bf^2 + cf^3$, f being the number of degrees of Fahrenheit, reckoning them from 212°, positive below and negative above this point of estimation.

By the above formula, thus elaborately investigated by M. Biot, Dr. Ure has computed the elastic forces of steam at the three successive temperatures of 232°, 262°, and 312°, or 20°, 50°, and 100°, above the boiling point of Fahrenheit's scale. First, we have $f = -20$ and $af + bf^2 + cf^3 = 20 + 400\,b - 8000\,c$; f is

negative, being above the point of departure 212°, and, consequently, the products af and cf^3 are positive, while bf^2 becomes negative.

$$\begin{aligned} 20\,a &= \ 0{\cdot}170824 \\ 400\,b &= -\ 0{\cdot}008324 \\ 8000\,c &= +\ 0{\cdot}000046 \\ \hline & \ 0{\cdot}162546 + \log. 30 \text{ or} \\ & \ 1{\cdot}477121 \\ \hline \text{Log. of } 43{\cdot}62 &= \ 1{\cdot}639667 \end{aligned}$$

By M. Biot's formula therefore at 232° F - - - -	43·620
M. Pouillet's table, at the end of vol. i. of Biot's treatise, computed in the above formula - - - - - -	43·500
Mr. Dalton's calculation - - - - - - -	43·25
Mr. P. Taylor's experiment - - - - - - -	43·00

At the temperature 262° Fahr.

$$\begin{aligned} f &= 50 \\ 50\,a &= \ 0{\cdot}4270609 \\ 2500\,b &= -\ 0{\cdot}0520272 \\ 125000\,c &= +\ 0{\cdot}0007250 \\ \hline & \ 0{\cdot}3757587 \\ \text{Log. } 30 &= \ 1.4771213 \\ \hline \text{Log. of } F_{262^\circ} &= \ 1{\cdot}8528800 \quad F_{262^\circ} = 71{\cdot}265 \end{aligned}$$

M. Pouillet's table - -	70·800
Mr. Dalton's calculation -	69·700
Mr. P. Taylor's experiment	72·50

At the temperature 312° Fahr.

$$\begin{aligned} f &= 100 \\ 100\,a &= \ 0{\cdot}854121972 \\ 10{\cdot}000\,b &= -\ 0{\cdot}208109100 \\ 1{\cdot}000{\cdot}000\,c &= +\ 0{\cdot}005800000 \\ \hline & \ 0{\cdot}651812872 \\ & \ 1{\cdot}477121300 \\ \hline \text{Log. of } F_f &= 2{\cdot}128934172 \quad F_f = F\,100 = 134{\cdot}57 \end{aligned}$$

Mr. Dalton's calculation -	125·85
Mr. P. Taylor's experiment -	159·45

The disagreement between M. Biot's formula and experiment, though trivial in the lower temperatures, will be observed to increase rapidly in the higher, which ought to render us very cautious in receiving similar algebraical representations. Nevertheless we feel pleasure in detailing the formula introduced by Dr. Ure and that by Mr. Creighton, as they are admirably adapted to express the force of steam between 32° and 212°, and also that by Mr. Southern, equally well fitted for the higher temperatures.

1. *Formula by Dr. Ure, for calculating the force of steam between* 32° *and* 212° *of temperature.*

The elastic force at 212°, = 30 inches, being divided by 1·23, will give the force for 10° below; this quotient, divided by 1·24, will give that for 10° lower; and so on progressively. To obtain the forces above 212°, we have merely to multiply 30° by the ratio 1·23 for the force at 222°; this product by 1·22 for that at 232°, and thus for each successive interval of 10° above the boiling point. Thus $30 \times 1{\cdot}23 = F_{222^\circ}$ $30 \times 1{\cdot}23 \times 1{\cdot}22 = F_{230^\circ}$ using F to denote the force at any temperature n, according to the notation of Laplace.

By departing from the point 210° F we shall obtain results equally accurate and more convenient for comparison with the experiments of Dr. Ure; and it is observed, that this latter rule may be better adapted to give the elastic force corresponding to any given temperature moderately distant from 212°.

Let $r =$ the mean ratio between 210° and the given temperature; $n =$ the number of terms (each of 10°) distant from 210°; F, the elastic force of steam in inches of mercury.

Then log. of F = log. $28{\cdot}9 + n$, log. r; the positive sign being

used above, the negative below 210°. Or by common arithmetic, multiply or divide 28·9 according as the temperature is above or below 210°, by the mean ratio, involved to a power denoted by the number of terms. The product or quotient is the tension required.*

* To render this process more intelligible to those who are not much accustomed to calculation, we subjoin the examples introduced by Dr. Ure.

Example 1.—*The temperature is* 140°. *What is the corresponding elasticity of the vapour from water heated to that point?*

140° is 7 terms of 10° each *under* 210°; 1·26 is the mean ratio $= \frac{1\cdot23 + 1\cdot29}{2}$; and consequently, $r = 1\cdot26$; $n = 7$.

$$\begin{aligned} \text{Log. } 28\cdot9 &= 1\cdot46090 \\ \text{Log. } 1\cdot26 \times 7 = 0\cdot10037 \times 7 &= -\ 0\cdot70259 \\ \hline & 0\cdot75831 \text{ which is} \end{aligned}$$

the logarithm of 5·732 inches
Experiment gives 5·77, leaving a difference of ·04, which is inconsiderable.

Example 2.—*What is the tenison of steam at the temperature of* 290°*?*

$$r = \frac{1\cdot23 + 1\cdot16}{2} = 1\cdot195 \quad n = \quad 8$$

$$\begin{aligned} \text{Log. } 28\cdot9 &= 1\cdot46090 \\ 8 \text{ log. } r = 8 \times 0\cdot07737 &= +\ 0\cdot61896 \\ \hline & 2\cdot07986 \text{ which is} \end{aligned}$$

the logarithm of 120·02 inches
Experiment gives 120·15.

Example 3.—*Temperature* 250°. *Force of steam in contact with water?*

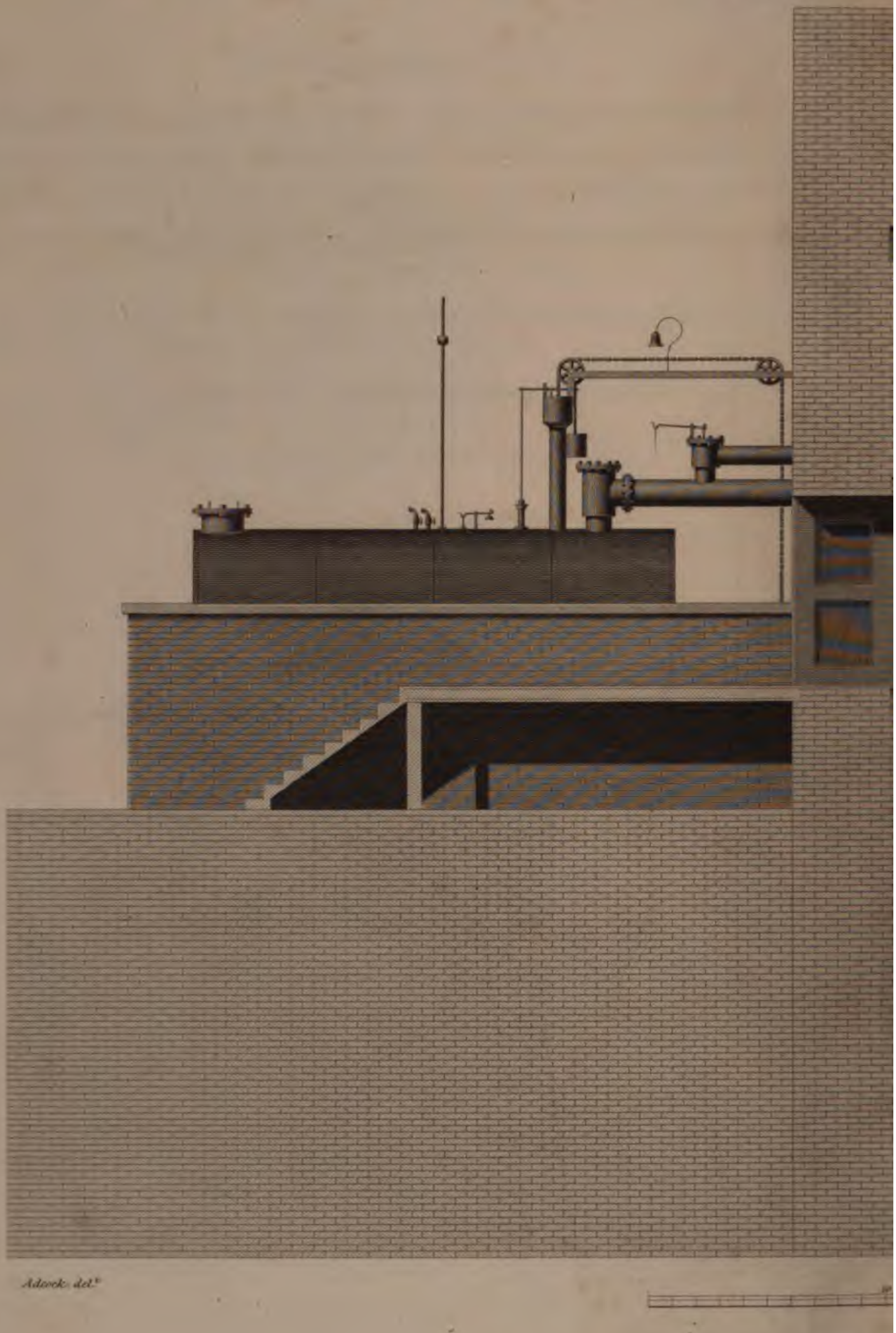
$$r = \frac{1\cdot23 + 1\cdot20}{2} = 1\cdot215 \quad n = 4$$

$$\begin{aligned} \text{Log. } 28\cdot9 &= 1\cdot46090 \\ 4 \text{ log. } r = 4 \times 0\cdot08458 &= +\ 0\cdot33832 \\ \hline & 1\cdot79922 \text{ which is} \end{aligned}$$

the logarithm of 62·98 inches
Experiment gives 61·90.

MESS^RS BOULTO

MACHINE À VAPE



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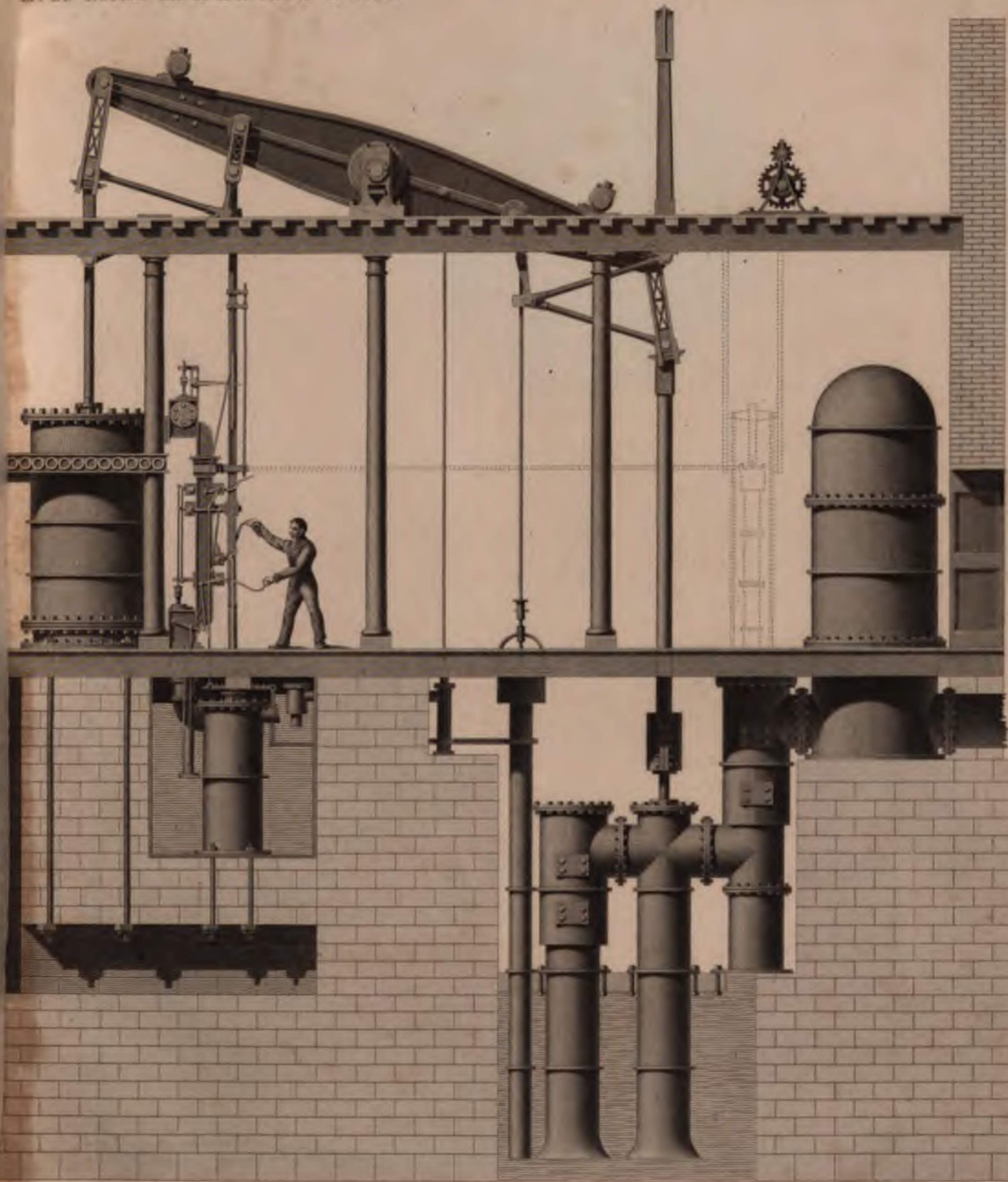
AND WATT'S SINGLE-ACTING ENGINE.

PLATE. V.

M^PLE ACTION DE M M BOULTON & WATT.



Scale of Feet.

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MESS^{RS} BOULTO

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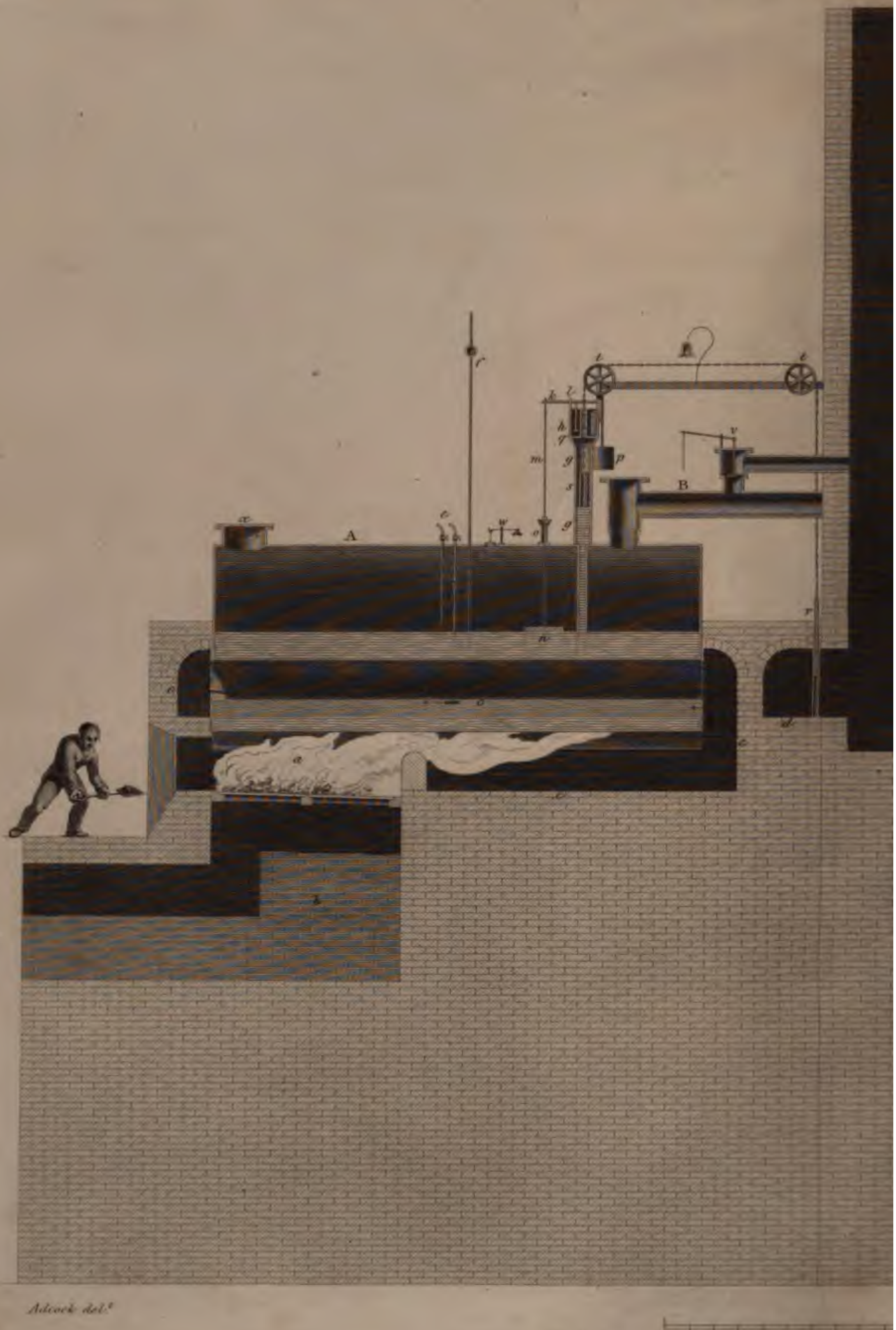

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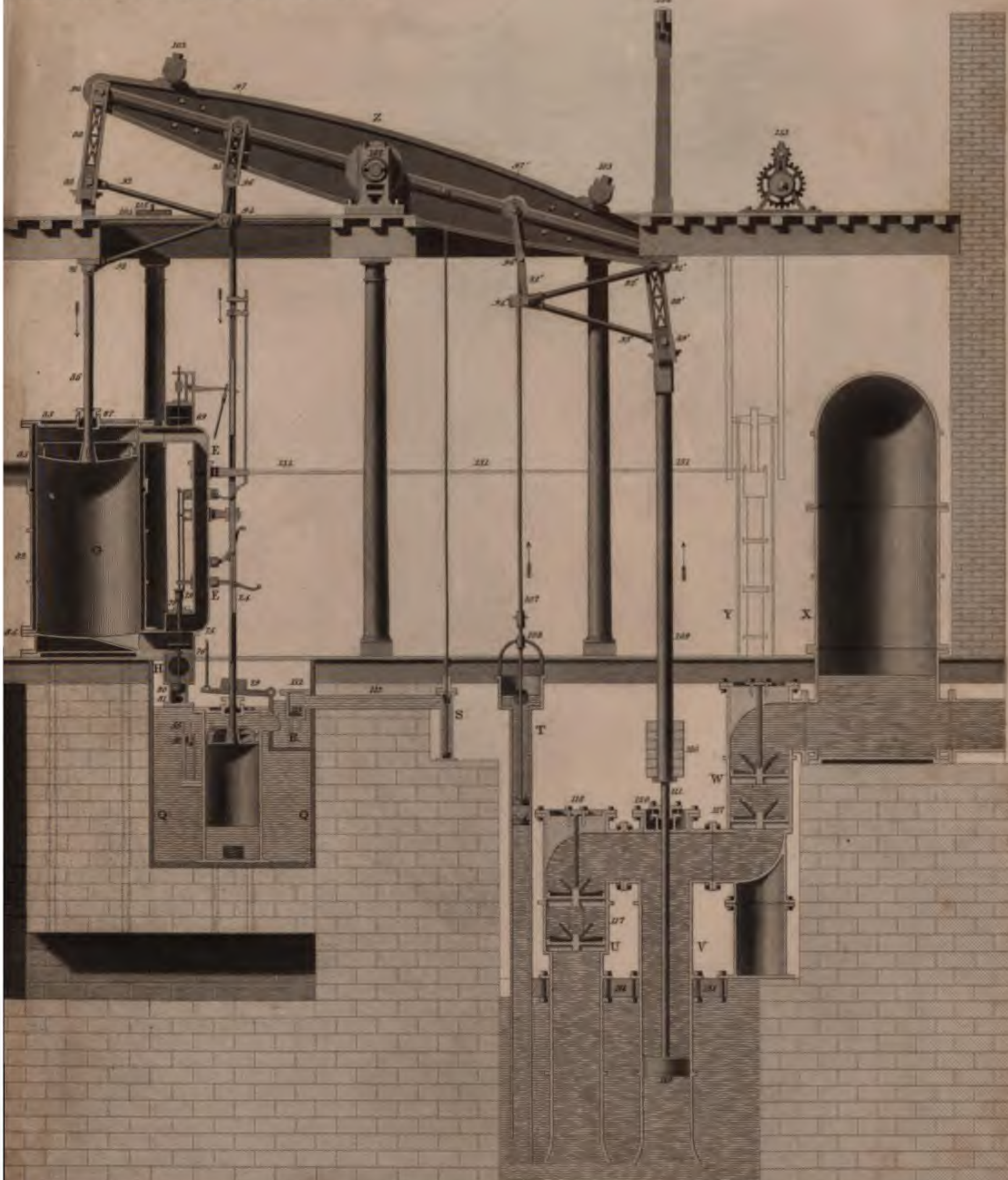
E. VI.

VATT'S SINGLE-ACTING ENGINE. PLATE VI.

LE ACTION DE M M BOULTON & WATT.



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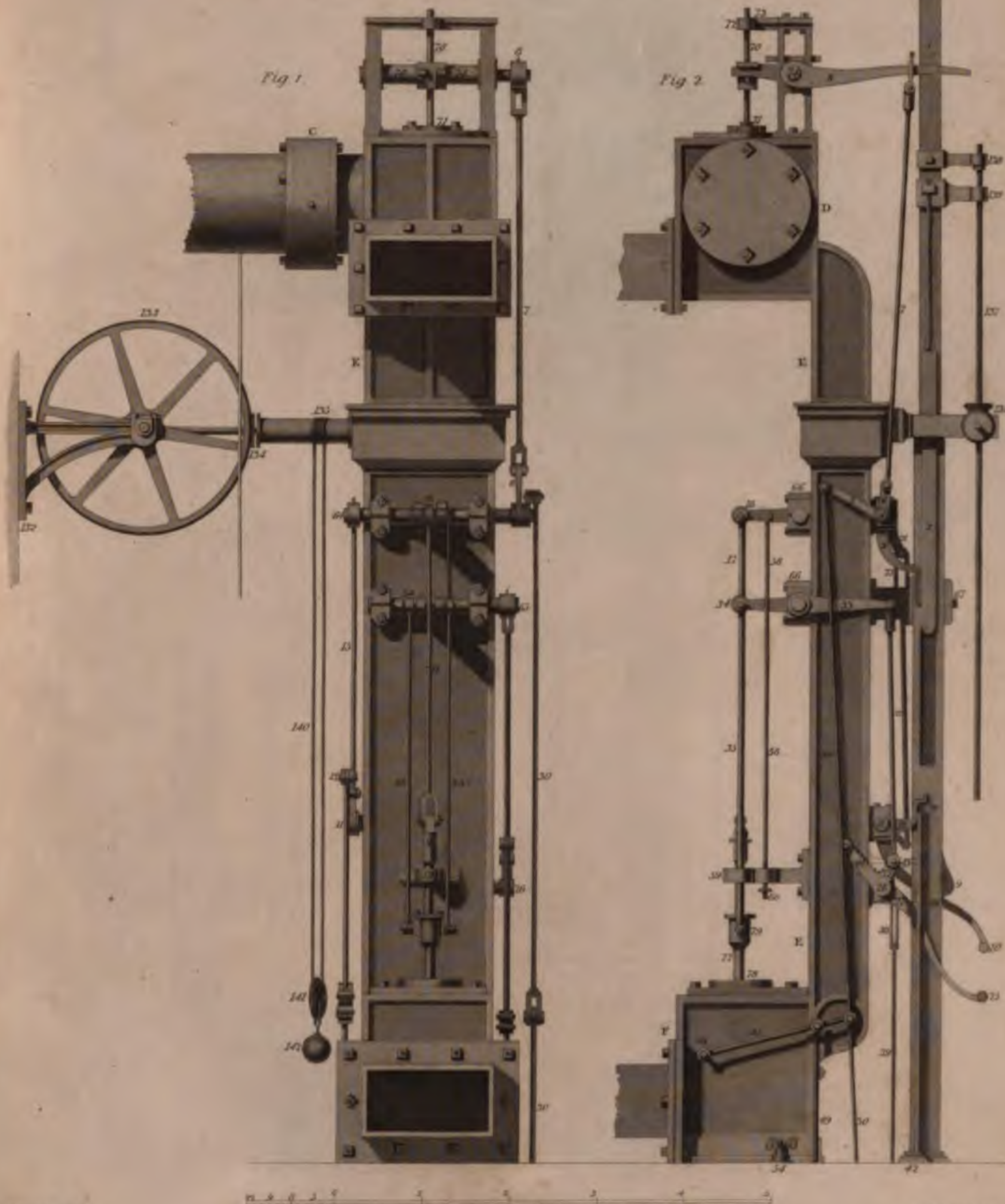
MESS^RS BOULTON AND WATT'S SINGLE-ACTING ENGINE.

MACHINE À VAPEUR À SIMPLE ACTION DE M.M. BOULTON & WATT.



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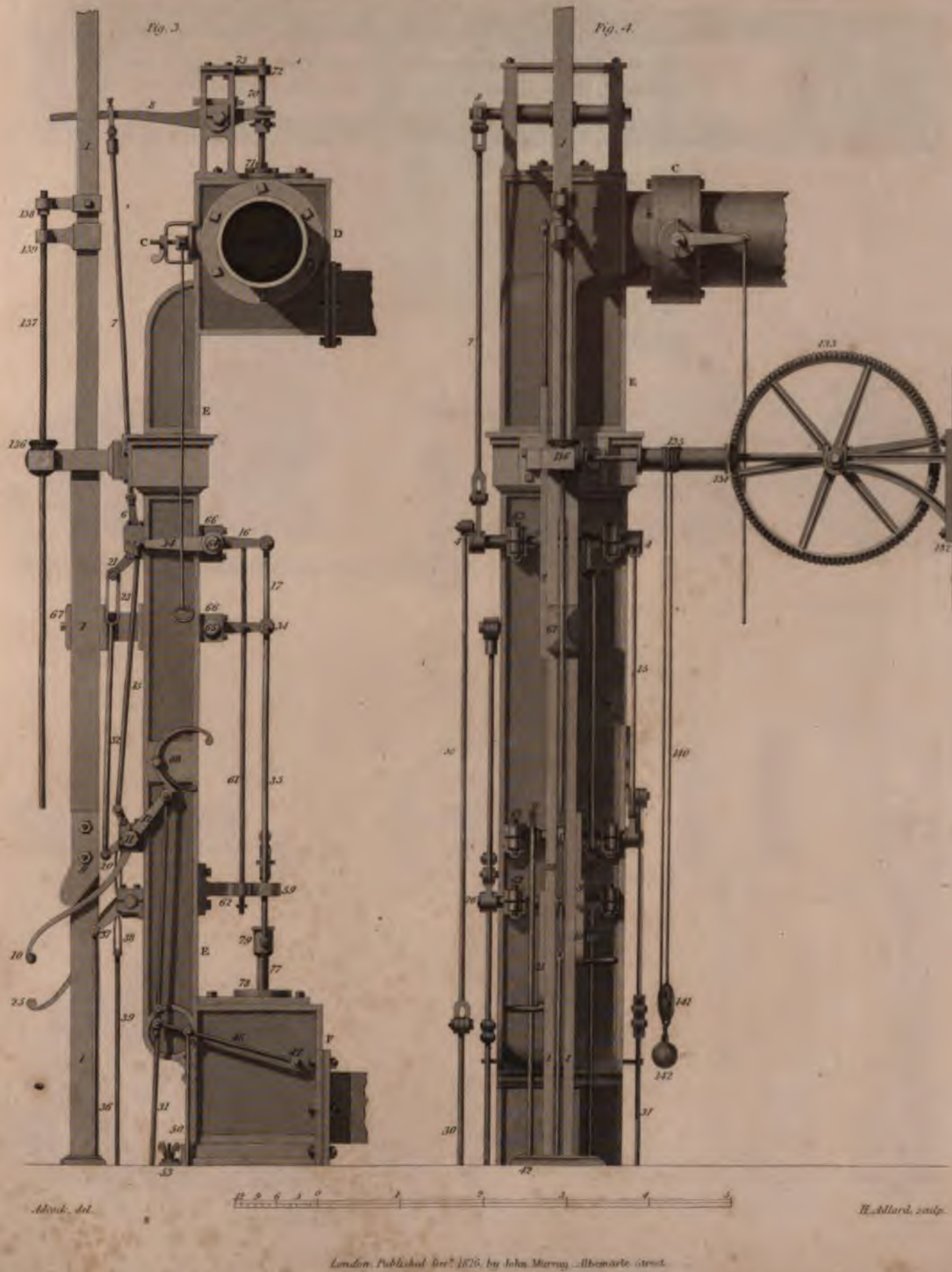
MESS.RS BOULTON AND WATT'S SINGLE-ACTING ENGINE. PLATE VIII.

MACHINE A VAPEUR A SIMPLE ACTION DE M.M. BOULTON & WATT.



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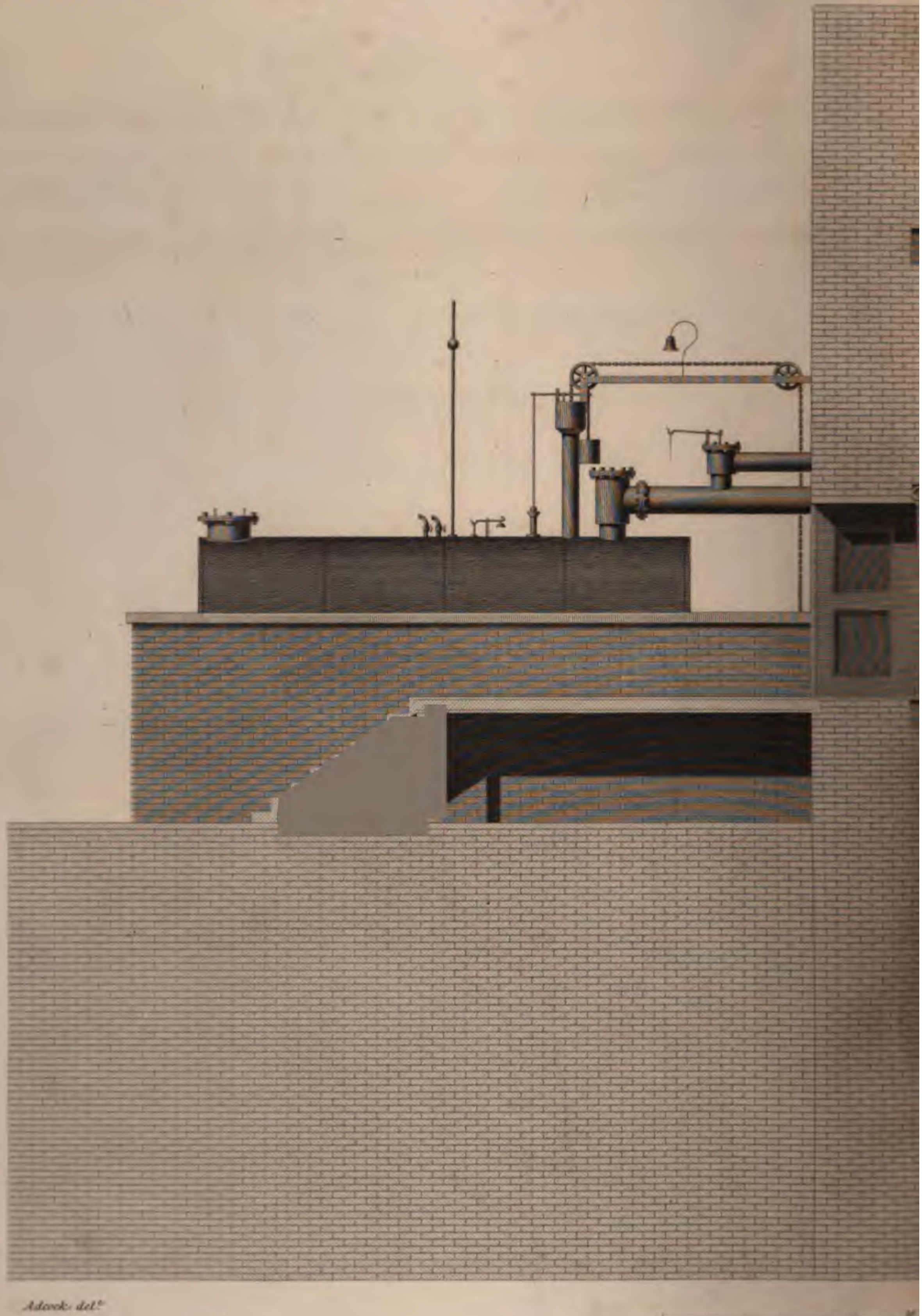
MESSRS BOULTON

MACHINE À VAPE



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MESSRS BOULTON AND WATT'S SINGLE-ACTING ENGINE.

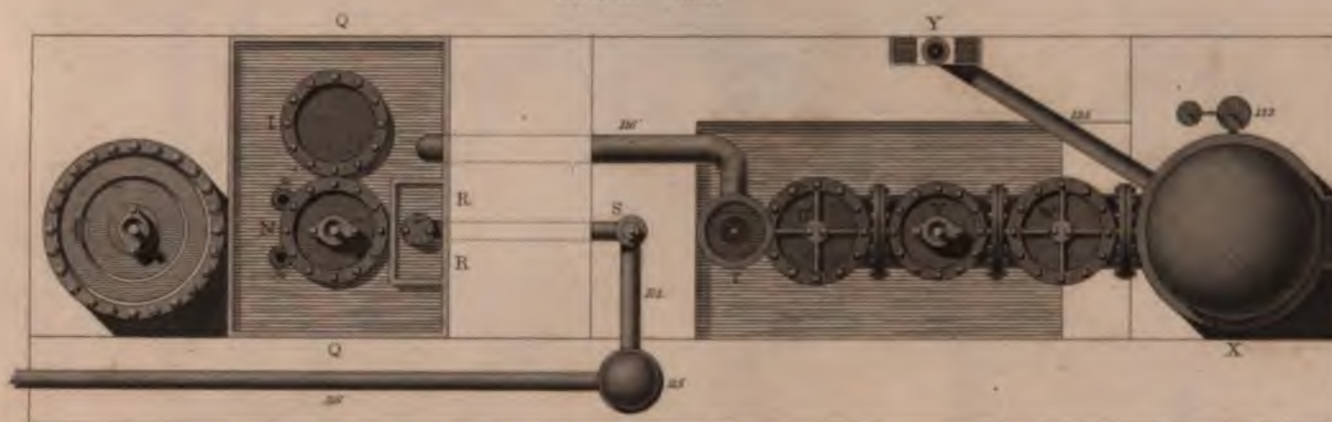
PLATE IX.

MACHINE À VAPEUR A SIMPLE ACTION DE M M. BOULTON & WATT.

Plan of Beam

Fig. 6.

General Plan



Details.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

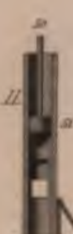


Fig. 12.

Fig. 13.

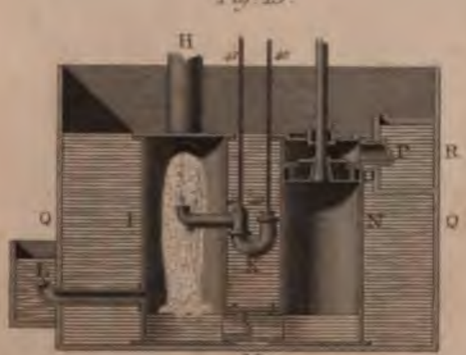
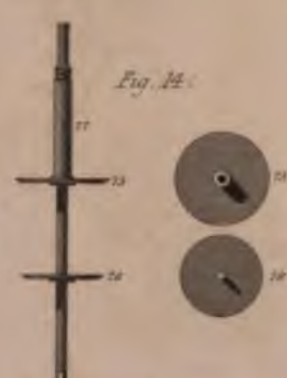


Fig. 14.



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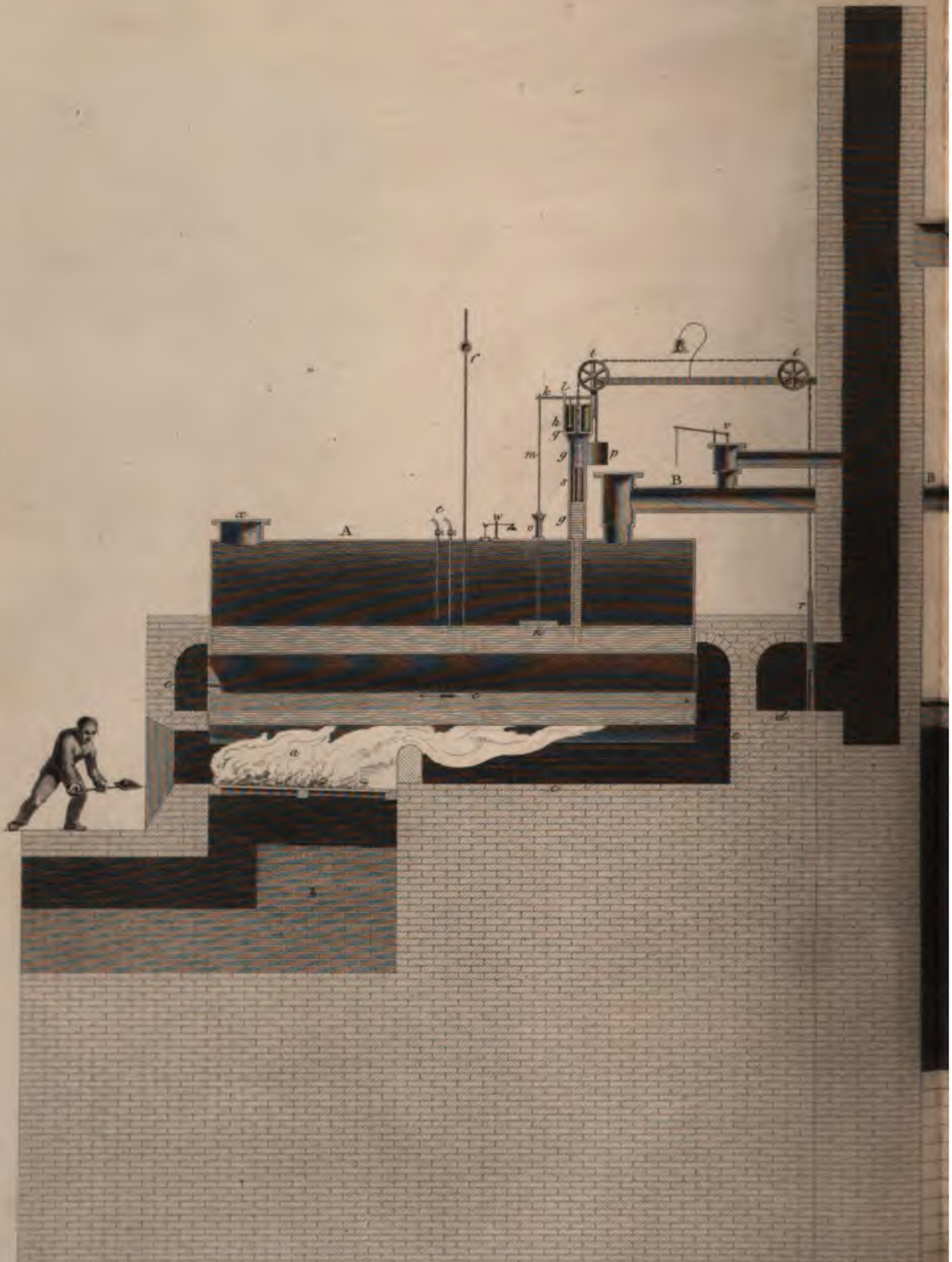

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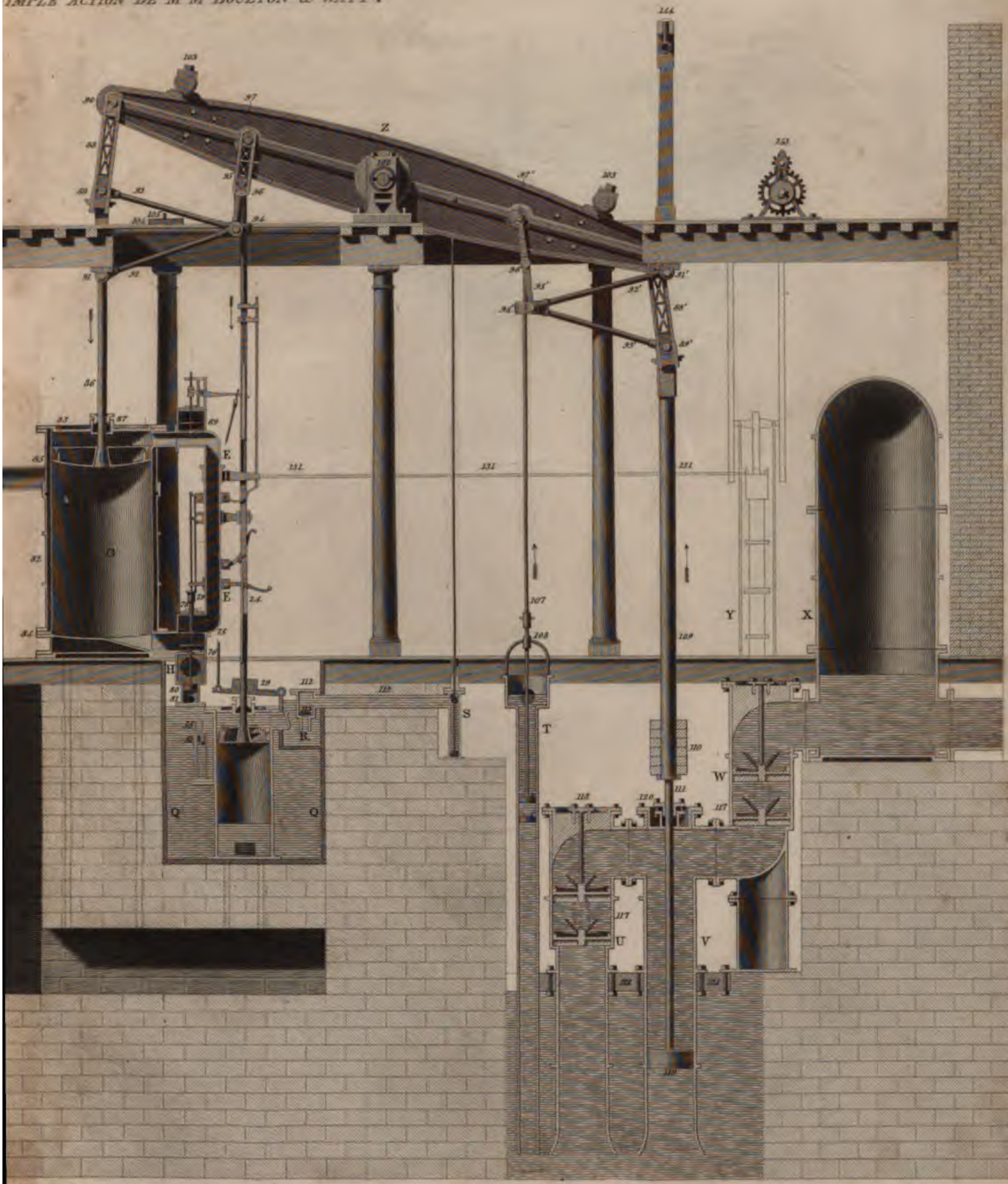
WATT'S SINGLE-ACTING ENGINE. PLATE. VI.

IMPLE ACTION DE M M BOULTON & WATT.



Scale of Feet.
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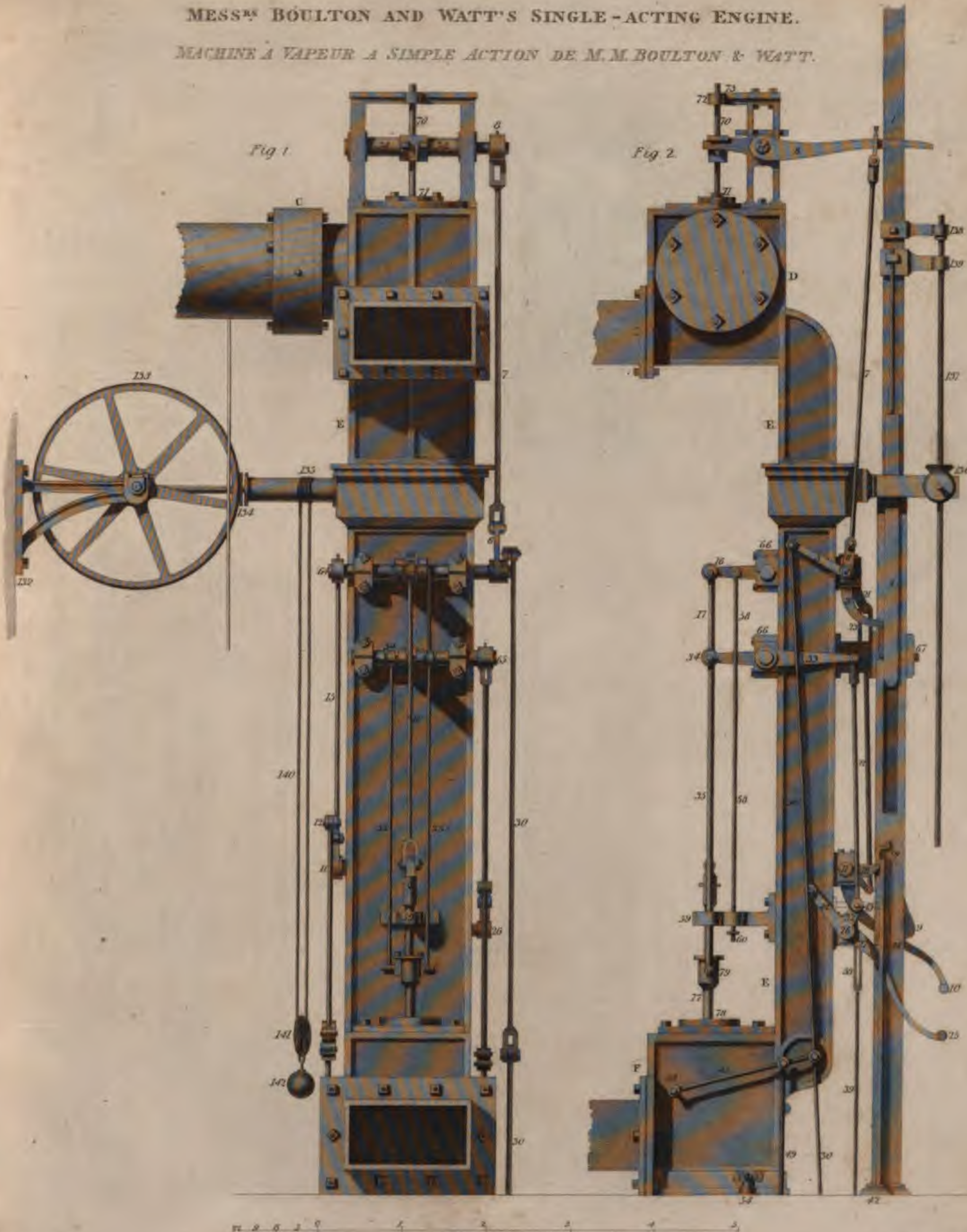

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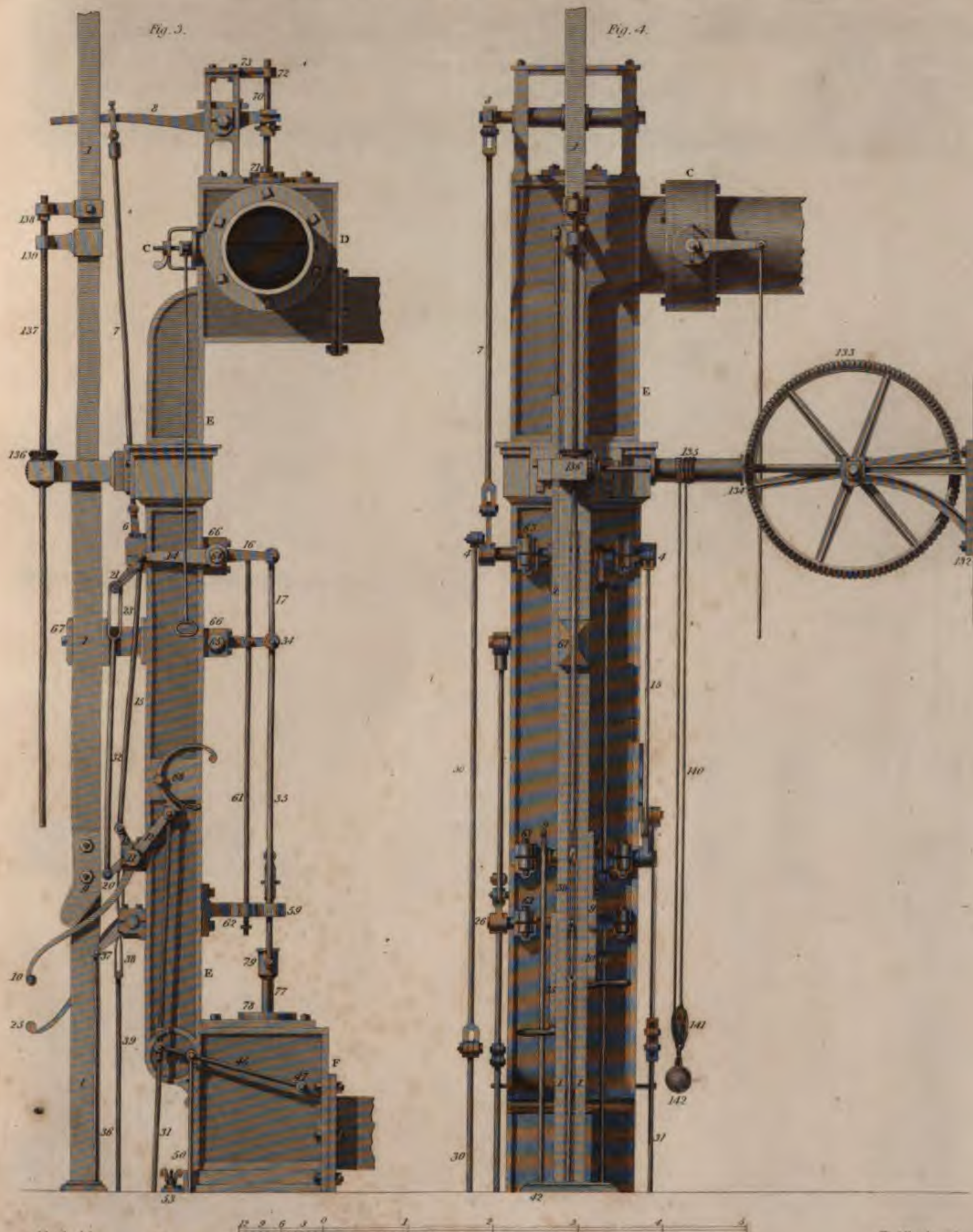
MESSRS. BOULTON AND WATT'S SINGLE-ACTING ENGINE. PLATE VIII

MACHINE À VAPEUR À SIMPLE ACTION DE M.M. BOULTON & WATT.



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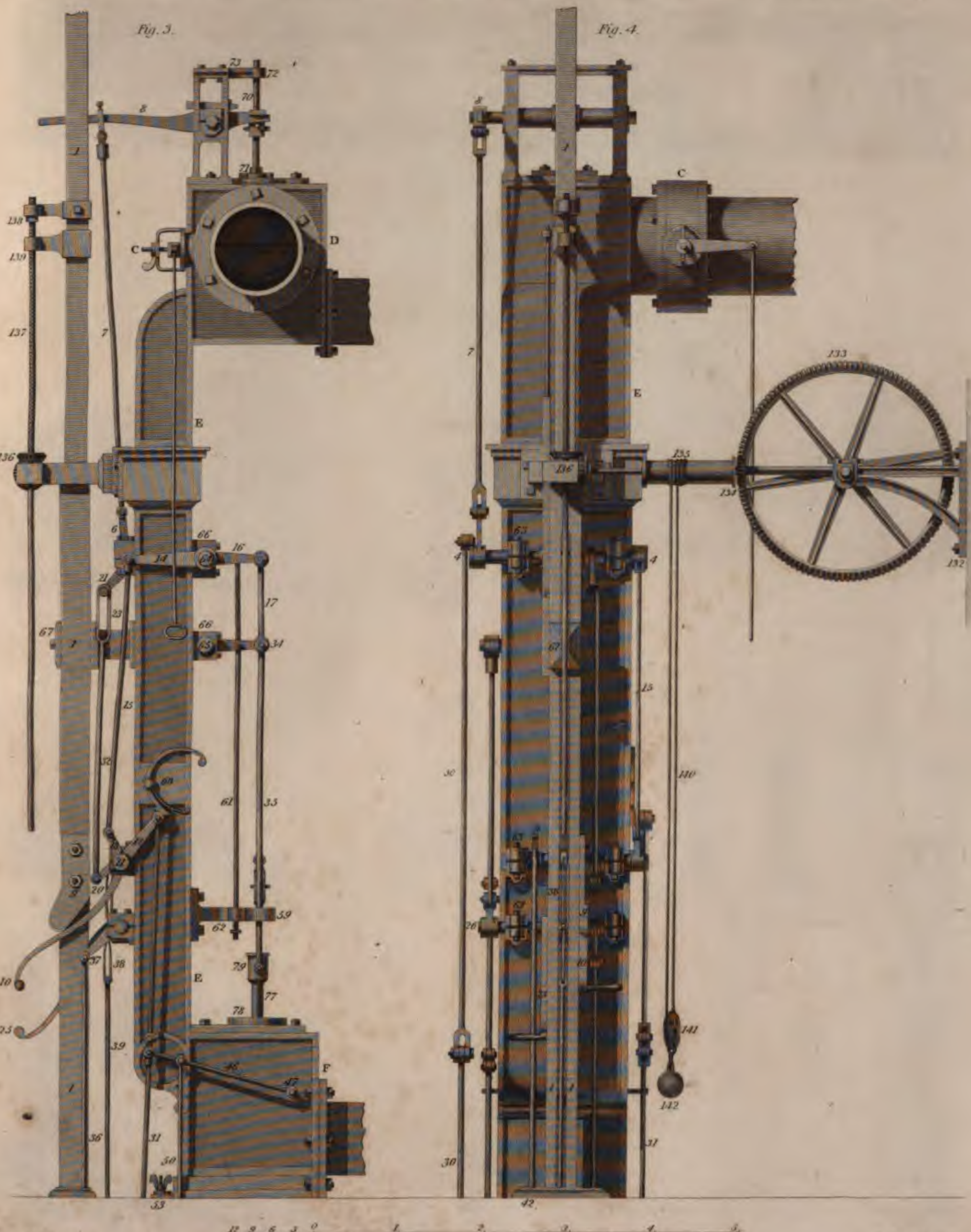
MESSRS. BOULTON AND WATT'S SINGLE-ACTING ENGINE. *PLATE VIII*

MACHINE À VAPEUR À SIMPLE ACTION DE M.M. BOULTON & WATT.



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MACHINE À VAPEUR A SIMPLE ACTION DE M M. BOULTON & WATT.

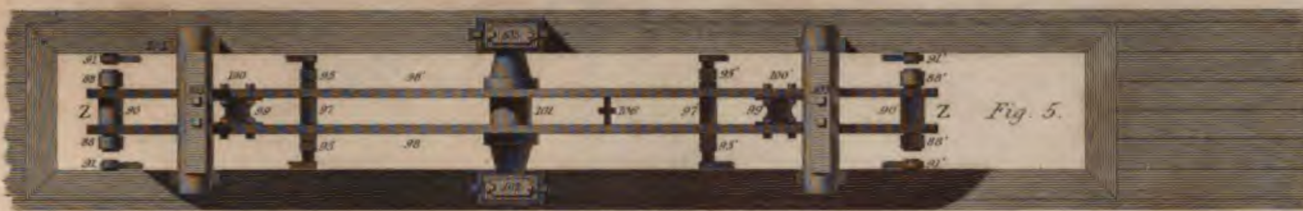
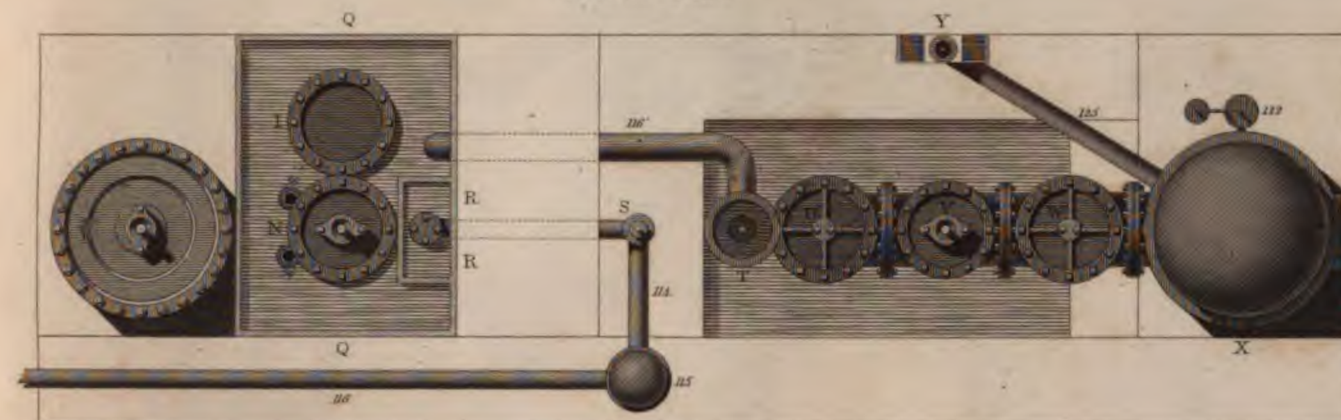


Fig. 5.

Plan of Beam

Fig. 6.

General Plan



Details.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

Fig. 12.

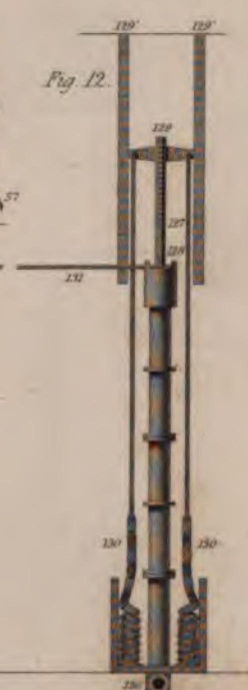


Fig. 13.

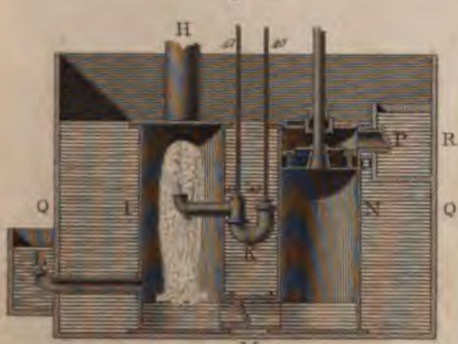
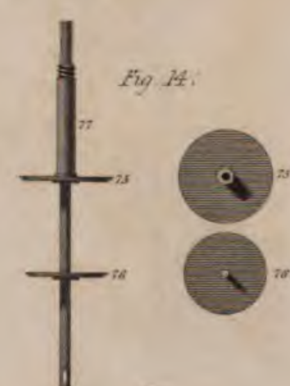


Fig. 14.



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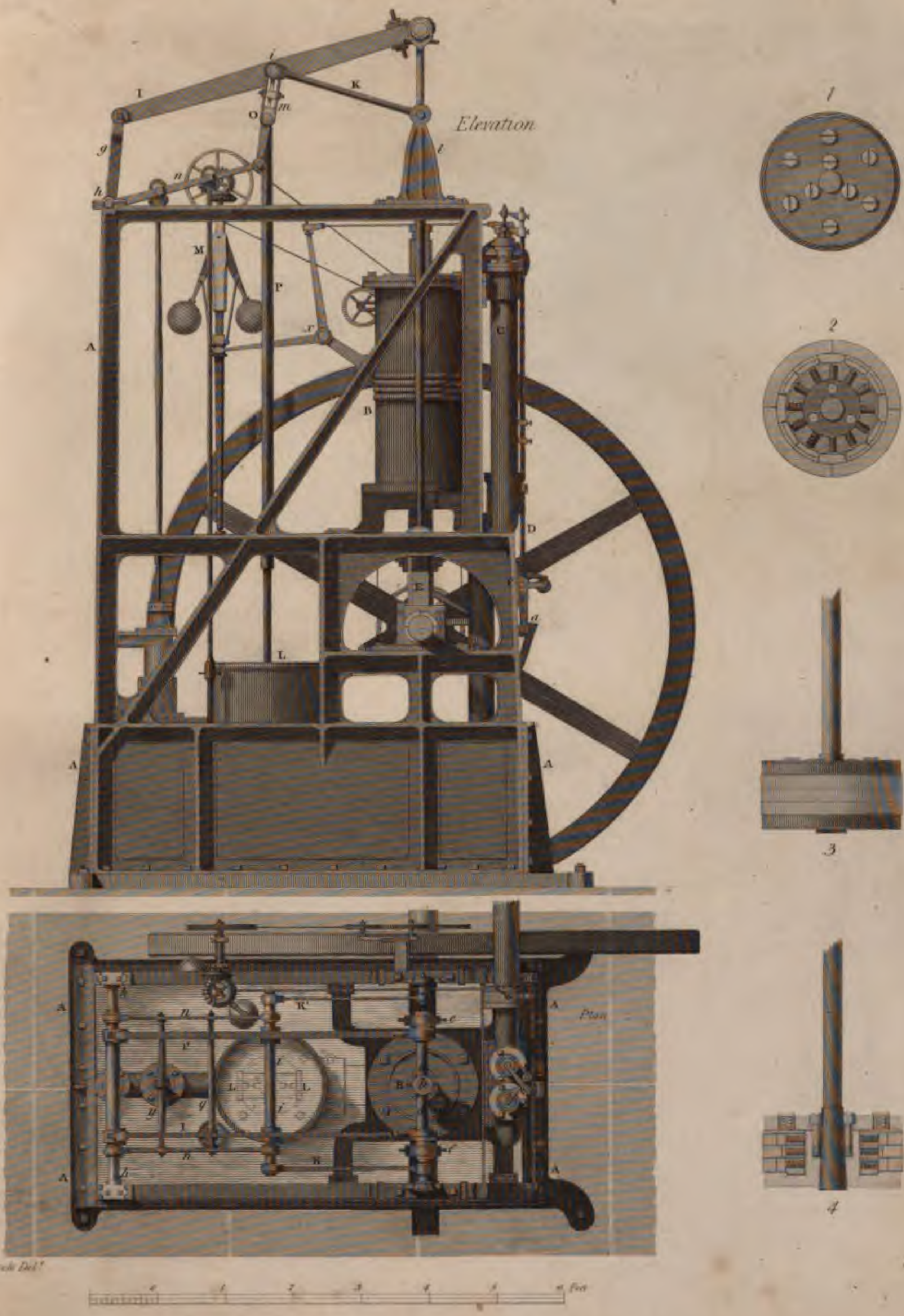
Mr. LLOYD'S ENGINE.

MACHINE À VAPEUR DE M. LLOYD.

PLATE



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H. Adlard Sculp.

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deferred, in consequence of a recent resolution of the Society of Civil Engineers, to institute immediately, under the direction of a select committee, an experimental inquiry into the comparative advantages of condensing and high-pressure engines. An account of the experiments and conclusions of this distinguished association, necessarily including the objects which we had in view, and giving, in all probability, a final decision to this important question, will enable us fully to accomplish the intentions of the dissertation above alluded to.

Although we do not profess to take an enlarged historical view of the origin and progress of the valuable machine which we so minutely describe, yet we propose to notice this subject in a Preface. We shall thus have an opportunity to do justice to the achievements of some of the earlier mechanics, whose merits, by no means inconsiderable, have been scarcely recognised amidst the superior splendour of one great modern improver. Our arrangement will however be found to be thoroughly historical, including only such of the progressive forms as still continue, whether partially or generally, to be employed.

Since engines for steam navigation constitute the most remarkable feature in their present application, they will receive particular attention, and their various modifications will be fully displayed. And near the conclusion of this undertaking, we shall notice, although much more cursorily, numerous alleged improvements, not yet acknowledged by engineers as effective machines, but principally recommended, on account of their peculiar fitness for propelling vessels and carriages, by their sanguine projectors and speculative admirers.

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PROSPECTUS.

It is intended that this Treatise on the STEAM-ENGINE shall be completed in Nine Monthly Parts; and as each Part will consist of Eight Quarto Plates, printed on the finest paper, and engraved in the most splendid manner, it will, when complete, represent in plan, elevatoin, section, and detail, the Engines of every celebrated maker.

The SECOND PART will appear in May.

LONDON:
Printed by W. CLOWES, Stamford-street.

No. 2.] *[Price 6s.*

THE

STEAM-ENGINE

THEORETICALLY AND PRACTICALLY

DISPLAYED.

BY

GEORGE BIRKBECK, M.D. F.G.S. M.A.S.

President of the London Mechanics' Institution, of the Meteorological and Chemical Societies, and of the Medical and Chirurgical Society of London; Honorary Member of the Literary and Philosophical Society of Bristol, Leeds, &c., &c., &c.

AND

HENRY AND JAMES ADCOCK,
CIVIL ENGINEERS.

ILLUSTRATED BY

A SERIES OF SPLENDID ENGRAVINGS

FROM

WORKING DRAWINGS MADE EXPRESSLY FOR THIS PUBLICATION.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.

MDCCCXXVII

ADDRESS.

The rapid progress of mechanical discovery, and the acknowledged wants of the practical engineer, have suggested the work now offered to the public. Of the Steam-engine, the most wonderful of human inventions, no delineation comprehending its most recent forms and applications has yet appeared; whilst all the graphic displays of the earlier constructions have been deficient alike in accuracy and detail. The explanations have been also exceedingly imperfect; neither conveying an adequate account of the actual performance of each kind of machine, so as to direct the choice of the inquirer, nor such measures of the various parts of engines of different powers, as to supply that information which might enable the artist readily to construct them. In the present publication these deficiencies will be completely obviated; and it will, consequently, form a manual or guide for the machinist, the manufacturer, the merchant, the statesman, and the philosopher.

A knowledge of the properties of steam being essential to the theoretical elucidation of the Steam-engine, the first part of the work will convey a copious, yet concentrated account of this agent, derived from the writings of the most able experimentalists. But the relative powers of steam, produced under pressure much greater than that of the atmosphere, not having been hitherto satisfactorily determined, a second dissertation devoted to the subject, will afterwards be introduced. An extensive series of experiments, which we have projected, was designed to supply the information requisite for this discussion: these experiments however will be deferred,

2. *Formula by Mr. Creighton, for calculating the force of steam between 32° and 212° of temperature.*

This empirical formula is remarkably easy of application.

Let D = degrees of Fahrenheit + 85; I = corresponding force of vapour in inches of mercury − 0·09.

Then 6 (log. D − 2·22679) = log. I.*

3. *Formula by Mr. Southern, for calculating the force of steam at any given temperature.*

Let t=temperature, e=elasticity, in inches of mercury; $T = t + 52$, and $E = e - \frac{1}{10}$, $m = 94250{\cdot}000000$:

$$\text{Then } \frac{T^{5\cdot14}}{m} = E$$

$$\frac{5\cdot14}{\sqrt{Em}} = T$$

But as this calculation is most easily performed by logarithms, let L signify the logarithm of the quantity to which it is prefixed:

$$\text{Then } 5\cdot14\, LT - 10\cdot97427 = LE$$

$$\frac{LE + 10\cdot97427}{5\cdot14} = LT$$

* *Example.—Required the elastic force of steam at 212° of temperature:*

$$\begin{array}{rl}
212 + 85 = & 297 \\
\text{Log. } 297 = & 2\cdot47276 \\
 & -\ 2\cdot22679 \text{ constant.} \\
\hline
 & 0\cdot24597 \\
 & 6 \\
\hline
 & 1\cdot47582 = \text{log. } 29\cdot91 = I \\
 & \qquad\qquad\quad +\ 0\cdot09 \\
\hline
 & \qquad\qquad \text{Inches } 30\cdot00
\end{array}$$

This is founded on the fact now fully ascertained, that the barometer indicates 29·8 inches when the temperature is 212°; but as, in order to facilitate computations, 30 inches of mercury are generally assumed to be the column which steam at 212° is capable of resisting, the following alterations must be made in the above algebraic expressions.

Let $T = t + 51{\cdot}3$; the index of the power and of the root be 5·13, instead of 5·14; and $m = 87344{\cdot}000000$: then the two last equations will be $5{\cdot}13\ LT - 10{\cdot}94123 = LE$; and $\frac{LE + 10{\cdot}94123}{5{\cdot}13} = LT$.

In order to render the account of the nature and effects of steam complete, the investigation should be pursued through temperatures considerably higher than those which the synopsis includes. The performance, however, of the requisite experiments is attended with great difficulty, and hitherto has exhibited results very far from satisfactory, neither the relative elasticities, nor the relative expenditure of caloric in producing them, having been distinctly ascertained. Experiments, calculated to afford greater accuracy, we have already projected; and others, with more extensive opportunities for prosecuting this difficult inquiry, are now actually engaged in it. The conclusions which may result from their researches will be found in a subsequent part of this Treatise.

THE STEAM-ENGINE.

MANY small machines, at various and even remote periods, were impelled by the power of steam. With the exception of the contrivance of Brancas, they were, however, little more than toys; and the application of this prime mover to the production of important effects, was first suggested about the middle of the fourteenth century, by the Marquis of Worcester. This suggestion, for such merely it must be considered, as we cannot discover any model, drawing, or practicable description, was followed in a few years by an actual steam-engine, the invention of Captain Savery.

ENGINE BY SAVERY.

PLATE I. AND II.

A representation of this engine, as employed for raising water, its original, and so far as applied by its inventor, its only object, is conveyed by the first Plate.

Two copper vessels, called boilers, are employed: they are set in furnaces of brick-work, so constructed, that the flame and heated air can circulate around them to the greatest advantage.

In the upper part of each boiler is a small cock, *a* and *b*, called gauge-cocks. These, by means of screws, may be removed, in

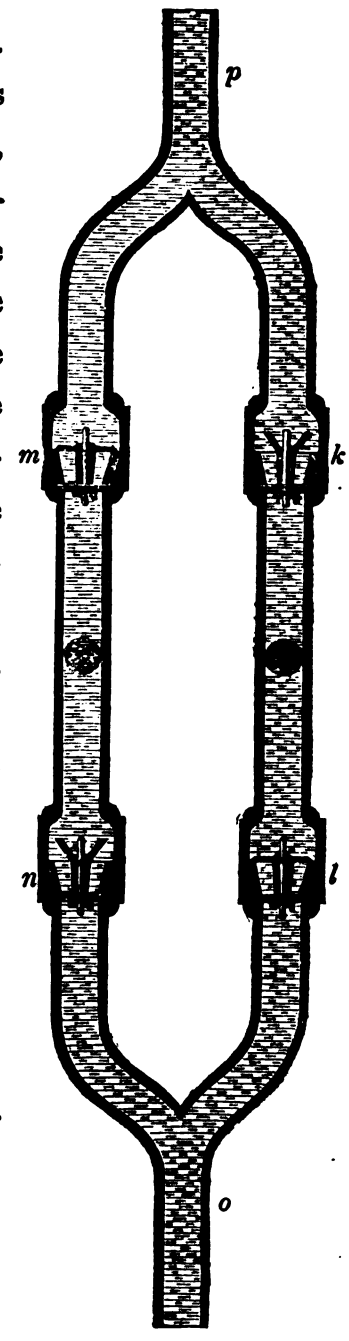
order that two-thirds of the quantity of water which it can contain may be introduced into the large boiler, and that the small boiler may be quite filled. The cocks are then replaced, and a fire is made beneath the great boiler, as represented in the engraving.

Two steam-pipes, *c* and *d*, proceed from the top of the boiler to the receivers *e* and *f*. These communications may be effectually closed, or opened and shut alternately, by an ingenious contrivance, represented, on an enlarged scale, in Fig. 2.

At the extremity of the lever connected with the bent handle *g*, there is a square hole to which a pin is adapted. The upper part of this pin forms a pivot, and works in a cross bar, *x*, which is supported by two screws, *y* and *z*, and the lower part passes through the lid of the boiler, having fixed to its extremity a brass plate, called the double slide valve, or regulator. This plate, being ground and fitted with great accuracy to the under surface of the lid of the boiler, prevents the escape of steam through either of the steam-orifices, C and D, which it may cover; and the attendant, by moving the handle *g*, is enabled to open and shut alternately the passages C and D; or by stopping the regulator between the utmost limits of its movement, the orifices of both pipes may, at the same time, be effectually closed.

From the lower part of the receivers, *e* and *f*, proceed two pipes, *h*, *i*, resting on the standards 1 and 2; and to these are screwed two other pipes, 3 and 4, branching off to the chambers *k*, *l*, *m*, *n*, in which are valves, as exhibited in the next page. Two other pipes, 5 and 6, connect the chambers, *k*, *l*, *m*, *n*, with the pipes *o* and *p*. The pipe *o*, which is called the suction-pipe, has its lower end

immersed in a well or reservoir of water; and the pipe *p* is denominated the force-pipe.



The action of this engine is very simple. The steam generated in the large boiler is allowed to accumulate in the upper part, until the attendant conceives that a sufficient quantity is collected to supply the engine. He then, by means of the handle *g*, removes the regulator from beneath the orifice of the steam-pipe *d*; this allows the steam to rush from the boiler into the receiver, *e*, whence, driving before it the whole of the air contained in the pipes and the receiver, it passes along the pipe, *h*, 3, through the valve, *k*, into the force-pipe, *p*, where it communicates with the atmosphere.

The air being thus expelled from the receiver, and its place occupied by steam, the attendant closes the communication with the boiler, and places the orifice of the cock, *r*, in such position, that a stream of cold water can be discharged from the cistern, *s*, upon the external surface of the receiver. This abstracts from the steam that portion of caloric which is necessary to maintain its elastic state; and as water, on its conversion into steam, is found to occupy a space about 1800 times greater than its former

bulk*, the condensation of the vapour must necessarily produce within the receiver a vacuum. Nothing, therefore, is left to counterbalance the atmospheric pressure on the surface of the water in which the bulb of the suction-pipe, *o*, is immersed; and as this pressure, when the vacuum is perfect, can raise a column of water to the height of 33 feet, the water ascends into the receiver, and fills it.

The receiver being thus filled, the lower clack-valve, *l*, closes. If the double slide-valve be now removed from the orifice of the steam-pipe, *d*, the steam will rush from the boiler, and drive the water from the receiver into the force-pipe, *p*, from which it cannot escape on account of the clack-valve, *k*.

That steam should press upon a liquid in the same manner as upon a solid piston, may to many appear surprising; but it should be recollected, that the specific gravity of steam, air, or any of the gases, is less than the specific gravity of liquids, otherwise they could not be maintained in a vaporous or gaseous state: and further, that as no fluid can descend through one which is much heavier than itself, steam cannot descend through water; the steam, entering into the receiver, must continue on the surface of the water, pressing upon every portion of it until the water is removed, and the receiver again filled with steam. Therefore, the attendant has only occasion to allow cold water to flow from the cock, *r*, upon its outer surface, to produce, as before, a vacuum, and to fill again the vacant space with water from the well.

* Dr. Desaguliers, in his Experimental Philosophy, has erroneously stated, that steam is 13338 times greater in bulk than an equal weight of water; and the writer of the article Steam in the Encyclopædia Britannica makes it upwards of 10000: it is, however, only 1800 times, as shewn in the Preliminary Dissertation.

Having thus exhibited the action of the engine as far as regards one receiver, it is very easy to conceive that, by means of the two steam-pipes and two receivers, an alternate effect may be maintained, and a constant discharge of water kept up at the top of the force-pipe *p*.

The quantity of steam consumed in maintaining the alternate actions of the engine, quickly reduces the water in the boiler; and as danger might occur from allowing the water to descend too low, the gauge-cocks, *a* and *b*, have been judiciously introduced. The gauge-cock *a* descends within the great boiler to about one-half of its depth; and the cock *b*, in the small boiler, to within eight inches of the bottom. When the attendant conceives that the great boiler requires to be replenished, he turns the handle of the cock *a*: if steam issues, the water is below that level, and the boiler must be supplied; but if otherwise, water is alone discharged.

When this trial indicates that a supply is required for the great boiler, the attendant kindles a fire beneath the small, or, as it is called, the subsidiary boiler. By placing this at the side of the large boiler, the water within is raised by the waste heat nearly to ebullition; consequently, it requires but a small addition of caloric to convert a sufficient quantity into steam to expel the water into the large boiler. The steam which is thus generated, having no opportunity to escape, depresses the water, and causes it to ascend up the pipe *t*, through the clack-valve 3, and along the bent pipe *u*, into the large boiler; and this discharge continues so long as the surface of the water is above the lower orifice of the pipe *t*, which is within eight inches of the bottom of the boiler. When it is below that point, the steam, in passing through the clack-valve 3, makes a rattling noise, and indicates that the small

boiler requires to be replenished. To effect this, the attendant turns the cock *v*, which, being connected with the inclined pipe *w*, admits water from the force-pipe.

In the year 1698, Captain Savery obtained letters-patent, securing to himself, during a certain term of years, the profits which might accrue from the manufacture of his engine. But not meeting with the encouragement which he expected, and to which, considering the utility of the invention, he was entitled, he was induced to publish a small treatise, entitled "The Miner's Friend."

In this treatise, pursuing a plan very different from his predecessor, the Marquis of Worcester, he exhibits an engraving of his engine, for the purpose of explaining its construction and manner of acting. This he accomplished in a very simple and satisfactory manner. With regard to the construction, he observes, that the flues of the furnace should surround the boilers in the shape of a worm or screw; and that wherever it is necessary to make a right angle in the chimney, a brick should be left loose, to remove whatever soot may be collected there. He further recommends, that the furnaces should be constructed of Stourbridge or Windsor bricks, or fire-stone; that the clacks, regulator, and cocks, should be made of brass; and the boilers and receivers of the best hammered copper. He also mentions the following purposes to which, in his opinion, it might be applied. First, to act as a motive power for every kind of millwork; secondly, to raise water for the supply of palaces, mansions, and private houses; thirdly, to furnish the requisite supply for cities, towns, and villages; fourthly, to drain fens and extensive marshes; fifthly, for ships; sixthly, to discharge water from mines; and seventhly, to relieve mines from foul and destructive damps and gases.

Although these prospective advantages are somewhat too extensive to have been realised, we cannot fail to admire the beautiful simplicity and excellent mechanical adaptation displayed by Captain Savery; qualities which appear more surprising, when contrasted with the rude state of the mechanical arts at that period. Indeed, when we look at the principle of this engine, along with its construction, and remember that it was the first, except the imperfect machine of Brancas, in which steam was actually applied as a moving power, we must award a high degree of praise to Captain Savery, for the perseverance and the talent which enabled him successfully to encounter his numerous difficulties.

The comparative simplicity of this engine affords a strong inducement for its adoption; but its application is, unfortunately, attended by a great waste of steam, and consequent useless expenditure of fuel. In order to drive the water from the receivers, *e* and *f*, into the force-pipe *p*, we have stated that steam must be admitted upon its surface. This steam possesses a sensible temperature, from 150° to 200°, higher than that of the water; consequently, by contact with it, a considerable portion is condensed, and thereby raises the surface of the water nearly to the temperature of ebullition. The extreme slowness with which caloric descends in fluids, allows the water to form a heated stratum between the steam and body of cold water. Then, rapidly accumulating in quantity, the steam, by compression, acquires sufficient force to expel the water into the force-pipe *p*, and, overcoming the weight of the column contained in the pipe, discharges an equal portion at the top. As the water descends in the receivers, a new source of condensation occurs; the steam comes in contact with suc-

cessive portions of the cold surface of the metal, and, according to Professor Robison, not less than eleven-twelfths of that which is generated in the boiler are thus uselessly expended.

Another imperfection, which operated against the introduction of this engine into mines, is the limited height to which, by suction, as it is improperly termed, and by the pressure of the steam, water can be raised. By suction, or, in other words, by the pressure of the atmosphere, water can be raised from 23 to 26 feet; and from the nature and strength of the materials of which it is composed, steam should not be applied to force the fluid to a greater height than 60 or 70,—an elevation amounting to about 16 fathoms. How inadequate this engine must be for the purposes of mining, is easily perceived. In Savery's time, some of the mines were, perhaps, not less than 100 fathoms deep; and, at the present time, several exceed 200 fathoms, or 400 yards.

To render the engine effectual for these depths, Captain Savery proposed that one should be erected at every 14 or 15 fathoms: but the expense of attendants, and the consumption of fuel, added to the annual expenditure for wear and tear, would, in this arrangement, exceed the expense incurred by the employment of horses. Besides, there is a liability that one engine should become deranged; in which case the works must cease, as all the other engines would be rendered ineffectual.

One of the improvements subsequently introduced into this engine is the safety-valve, the invention of M. Papin, a native of France, which we shall have occasion to describe fully hereafter: and another improvement is the production of a vacuum by introducing the injection-water into the receiver.

In describing the action of the engine, we have stated, that when the steam filling either of the receivers is to be condensed, cold water is discharged from the cock *r*, upon its external surface. On attentively considering this process, it will be perceived that, as the caloric of the vapour must pass through the receivers, its abstraction and the consequent condensation must be slow; whilst, by dashing cold water into the receiver to mingle with the steam itself, an almost instantaneous condensation occurs. This method of applying the injection-water is ascribed to Newcomen, and is stated to have originated from an accidental observation. Dr. Desaguliers, in his Experimental Philosophy, says, that on the erection of the first atmospheric engine, in 1711, and which was one year prior to the expiration of Savery's patent, the engine was observed to make several strokes in unusually quick succession; and that, upon searching for the cause, a small hole was discovered in the piston, which allowed cold water to fall into the cylinder, and thereby condense the steam.

Although in the *Miner's Friend*, to which we have alluded, Captain Savery has suggested that his engine might be applied to produce a rotatory motion for impelling mill-work, it is not probable, from the limited state of our manufactures, that he had ever an opportunity of carrying his ideas into practice. This has been subsequently effected by Mr. Peter Keir, an ingenious and intelligent engineer, residing at Camden Town.

ENGINE BY MR. PETER KEIR.

PLATE III.

THE action of this engine is very similar to that originally constructed by Captain Savery; but the water, after having been received into a cistern, is discharged upon an overshot-wheel, to produce a rotatory motion.

A represents a wrought-iron boiler 7 feet long, 5 feet wide, and 5 feet deep. B, a cast-iron pipe, fixed to the top of the boiler, through which the steam is conveyed to the steam-chamber C. This part is seen enlarged in Fig. 4, on a scale of two inches to the foot. In the inside of this chamber is fixed a bracket, to support the frame marked *m*, which is grooved, that the back part of the rack, *n*, may slide up and down in it. To the lower part of the rack, a stem, connected with the top of the valve *a*, is jointed; so that when the axis, *b*, is turned partly round, it will, by the movement of the sector, *c*, and rack, *n*, raise the valve from its seat. In Fig. 5 is shown a plan of the axis *b*, the sector *c*, the rack *n*, and the grooved frame *m*, in which it moves. On each side of the steam-chamber, a strong bosse is cast. One of these has a hole drilled into, but not completely through it, to receive the pivot at the end of the axis, *b*; and the other has a conical hole passing through the metal, that the conical part, *q*, of the axis may be fitted into it, by carefully grinding them together. This makes the junction steam-tight, when it is pressed home to its bearing, by the

screw *r*. The screw is tapped into the cross-bar of the bridle *s*, and acts, as is easily understood, on the end of the axis.

Below the valve, *a*, a cylinder, *o o*, of gun or bell metal, is placed in a space formed to receive it, and to this the valve *a* is accurately fitted, to make it steam-tight. Across the centre, a bridle, *p*, is carried, having a hole, through which the stem passes, to preserve the valve in a vertical position. The upper part of the steam chamber has a cover, termed a bonnet, firmly fixed by two screw-bolts.

In Fig. 1, F represents a reservoir of water, into which is immersed the lower part of the pipe, D E. This pipe rests upon a foundation of brickwork, and the water passes through apertures, represented by dotted lines, which are guarded by a sieve of copper wire. The valve *d*, at the lower part of the pipe, is shown in plan, on an enlarged scale, in Fig. 6.

d d is a frame formed by the outward ring and six radial bars, which, meeting at the top, are jointed to a centre piece. Each of these bars forms an angle of about 30° with the plane of the rim: *t t t t t t* are six leaves, jointed by common hinges to the frame. These leaves rest upon the bars, and offer very little obstruction to the ascent of the water.

The upper reservoir, or pentrough, G, receives at every stroke of the engine the whole of the water raised in the pipe, D E, above the line H. To allow sufficient room for the water to flow from the vertical pipe to the cistern, the passage *e* is made rectangular, and is in breadth equal to the diameter of the pipe. A horizontal section of the pipe, at the dotted line *k l*, is exhibited in Fig. 2.

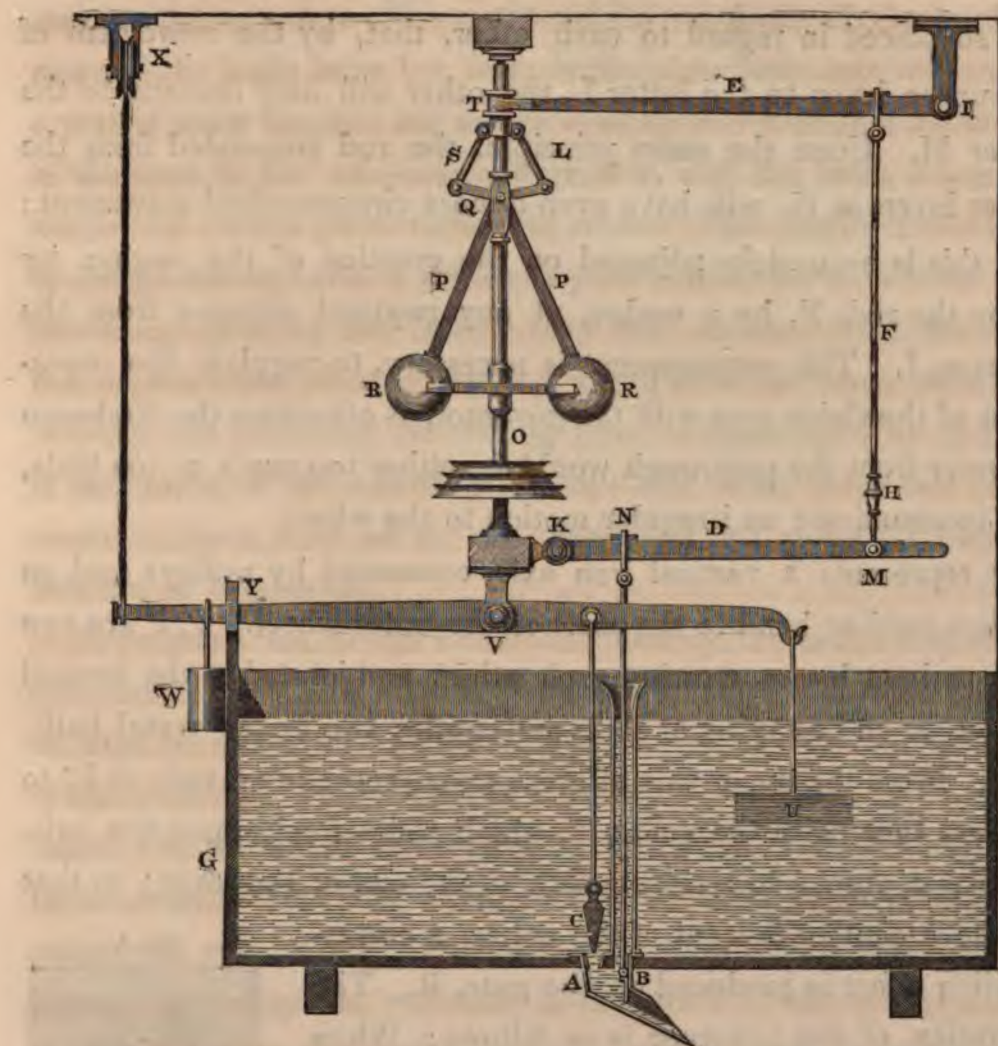
At the extremity, *e*, there is a hanging valve, called the delivery

valve, moving on a joint or hinge, to prevent the return of any water from the pentrough. That this valve may not open more than three inches, a wrought-iron stay is fastened to the side of the pentrough, G, and bent over the valve somewhat in the form of a bird's claw. This precaution is necessary, to hinder, by the immediate closing of the valve, the return of water into the receiver, D H, and to prevent the valve, on the formation of the vacuum, from striking too violently the pipe *e*, which, if frequently repeated, might destroy the engine.

The discharge of water from the pentrough is regulated by a governor. This, we believe, was its first application to a water-wheel; but since its introduction by Mr. Keir, several have been employed in different parts of the kingdom. The mode by which it was effected is represented in the engraving in the next page.

In the bottom of the pentrough G there is a rectangular aperture, 24 inches long, and 12 inches wide, and to this is adapted a cast-iron shute, A. The cast-iron plate on the top of the shute, seen in plan, on an enlarged scale, in page 64, has a hole, bevelled off, to receive the wedge-shaped shuttle, C. It has also two circular perforations, for the pipes *e* and *f*. To prevent any escape of water from the pentrough, when the shuttle is closed, the sides of the bevelled aperture are covered with dread-nought *, and the pipes *e* and *f* are carried above the surface of the water. The rods which suspend the sluice-gate B pass through these pipes, so as

* This is a piece of coarse cloth, such as is used for the coats of watchmen, saturated with a mixture of white lead and oil, to render it impervious to water. It is much used to secure the joints of hydraulic engines, and is preferable to leather, as it is only affected by very high degrees of temperature.



to work without friction, and are attached to the lever D. This lever is connected to the lever E by a rod F, which can be lengthened or shortened by a swivel and regulating-screw, marked H. By shortening the rod, the gate is raised to the required height to produce the rotation of the wheel: afterwards, the discharge of water is regulated by the centripetal and centrifugal forces of the governor.

The levers D and E are movable on centres or fulcrums I, K, and

are so placed in regard to each other, that, by the movement of the upper lever to the letter L, the other will only descend to the letter M. Upon the same principle, the rod suspended from the lower lever, at N, will have even a more circumscribed movement; and this is accurately adjusted on the erection of the engine, by fixing the rod, F, by a wedge, at any required distance from the fulcrum, I. This arrangement is necessary, to regulate the movement of the sluice-gate with the governor, as otherwise the discharge of water from the pentrough would be either too much or too little, and communicate an irregular motion to the wheel.

O represents a vertical iron axis, connected by pulleys and an endless cord or band to the shaft of the water-wheel. P, P are two arms or bent levers, crossing each other, and jointed to the vertical axis at Q, and carrying at their extremities two heavy metal balls, R, R. From the upper part of these arms proceed two rods, S, L, to connect them with the collar, T, which slides freely upon the axis, and has a groove to receive a fork at the end of the lever; so that by the ascent or descent of the collar, a corresponding effect is produced on the gate, B. The operation of the governor is as follows: When the vertical axis is put in motion, the balls, R, R, recede from the axis, and revolve at the same distance from it, so long as the velocity of the axis remains the same; but when the velocity is accelerated or retarded, they fly farther from, or approach nearer to, each other. The tendency of the balls to fly outwards, by the combination of two oppositely acting forces, increases in the same

Fig. 2.

ratio as the velocity. When the velocity is small, the arms which suspend the balls have but little inclination, and therefore support a part of their weight; but as the velocity increases, the inclination of the arms to the axis becomes greater, and the balls, being less supported, exert a greater effort to return. The weight or tendency of the pendulous balls to return may be considered as a constantly increasing quantity the further they are removed from the axis: but as the balls, when describing a larger circle, have additional velocity, the increasing gravitating force is opposed to an increase in the ratio of the centrifugal force; and when these two forces counterbalance each other, the motion of the governor becomes uniform, or is constant.

To preserve this motion a constant quantity, it must be understood that the impelling and resisting forces continue the same; but as, in all kind of mill-work, the labour is ever varying, and certain parts of the machinery are repeatedly thrown in and out of gear, the velocity of the impelling force varies by being opposed to a greater or less resistance. Therefore, as the water-wheel of this engine makes ten revolutions per minute, and the governor from sixty to seventy, the slightest variation in the speed of the wheel will be communicated to the lever; and this, elevating or depressing the sluice-gate, will allow a greater or less quantity of water to fall on the wheel.

The great friction attendant upon the movement of the common shuttle long prevented the application of the governor to the water-wheel, and many unsuccessful attempts were made to adapt it to this purpose. We must, therefore, express our approbation of the simple and ingenious manner in which it has been effected by Mr. Keir.

Besides the rods and levers connected with the sluice-gate, B, there is another lever, marked Y, and movable on the fulcrum V, adapted to the pentrough. From one end of it is suspended a float, U, of Portland stone, and from the other end an iron weight, W. The weight, W, being equal to the difference between the specific gravities of the float and the water, allows the stone to remain suspended in the water at the end of the rod which connects it with the lever; but when the surface of the water has descended below that level, the gravity of the stone exceeds that of the weight, W, and, causing the lever to preponderate, closes the wedged-shaped shuttle, C.

When the attendant has occasion to stop the wheel, he lifts the weight, W, which is easily performed by means of a cord passing over the pulley, X. By this action, the float, being relieved from the counter-weight, descends in the water, through a space proportionate to the height to which W has been raised, and which is sufficient to close the sluice. By releasing the weight from the cord, the stone-float again ascends, and reproduces the motion of the wheel, by allowing water to flow from the pentrough.

If it had been required simply to raise and depress the sluice-gate, other and much easier modes of effecting it might have been devised; but as it is necessary to keep the delivery-valve at the end of the pipe, *e*, in Plate III., covered with water, to prevent the admission of air into the receiver, contrivances were resorted to, that the sluice might close when the surface of the water descended to a certain level. This stops the action of the wheel and engine, and indicates either that the steam has got too low, or that some other circumstance requires prompt attention.

I K, Plate III., is an overshot-wheel, 18 feet in diameter, and 2 feet wide. The gudgeons rest on plummer-blocks, one of which is shown fixed on the bearing, L. The shaft or axis, on the opposite side of the wheel, passes into the manufactory, and there gives motion to the machinery connected with it.

To the right of the plummer-block is shown an end view of a solid wooden wheel, marked *f*, and a plan of it is given in Fig. 3. *g g* are cleats, fixed to the back of the wheel; and in the centre of the space between each cleat, but on the face or front of the wheel, blocks, *h h*, are fixed, so that there are always as many blocks on the face as there are cleats on the opposite side. These cleats and blocks, which may be varied in number as occasion may require, serve to elevate and depress a series of levers, that open and close, at the required time, the steam-valve, *a*, the air-valve, *i*, and the injection-cock, which could not be exhibited in the section.

When the various parts are combined, and a sufficient quantity of steam is generated, the attendant takes hold of a rod connected with the axis, *b*, of the sector, and pressing it upwards, opens the steam-valve, *a*. This permits steam to enter the receiver, D, and discharge, through the delivery-valve at the end of the passage, *e*, that portion of the air which was contained in the space, D H. He then, by similar means, introduces a jet of cold water to condense the steam, and form a partial vacuum, so that the atmosphere, pressing upon the water in the reservoir, F, causes it to ascend to a height corresponding to the length of the column of air which has been displaced. Another portion of the air still remaining in the pipe, D E, is thus brought within the space, D H; therefore, by repeating the operations, the whole of the air is eventually

discharged through the valve, and the water rises in the pipe as high as the letter D.

On the first erection of the engine, Mr. Keir conceived that, by admitting steam of one or two pounds pressure upon the surface of the water in the pipe, D H, the water would rapidly descend into the cistern, G; this, however, was not the case. The rapid condensation of the steam when in contact with the water, accounts for this occurrence. It is evident, that little or no discharge of the water could take place until the surface had been heated nearly to the boiling point, when the steam would counterbalance or exceed the atmospheric pressure, and allow the water to escape, by its gravity, through the passage, *e*.

The slowness of operation, and the great waste of steam dependent upon this mode of construction, were subsequently obviated by admitting, previously to the entrance of the steam, a small quantity of air through the air-valve, *i*, into the upper part of the pipe, D E. It still, however, remains a subject for investigation, whether the air so admitted forms a stratum between the surface of the water and the steam, or whether, by admixture, it suddenly becomes expanded by the caloric of the steam, and thus, by an increase of elasticity, expels the water more forcibly through the pipe *e*. In whatever way it may act, it is certain, that the water does not pass out of the receiver, D, by its weight alone, but is ejected with a force much superior to it. In proof of this it may be stated, that the quantity thrown out at each stroke is not only equal to the capacity of the receiver, D H, part of which is below the surface of the water in the pentrough, G; but the water so expelled is accompanied by air, as may be observed by the bubbles which rise to its surface.

Mr. Keir has judiciously provided for this, and constructed the joint or hinge of the delivery-valve in such manner, that, when open, it allows the air freely to escape.

The boiler of this engine is replenished by a self-acting feed-pipe, the action of which is well known to those who are familiar with the steam-engine. The method is not exhibited in this engraving, and the account of it will therefore be deferred until we describe the single-acting engine by Boulton and Watt.

When cisterns are employed, and the same water is continually raised, it necessarily becomes heated. This, at first view, would appear to be very advantageous, by lessening the wasteful condensation of the steam within the receiver; but Mr. Keir finds, that the consumption of fuel is nearly the same whether the water be at 40 or 150 degrees of temperature. He also finds, that the heated water has a destructive effect on wood, insomuch that within the space of twenty-eight years, two wheels and two pentroughs made of the best oak were destroyed. This deserves particular attention, and shows the necessity of using iron, lead, or copper, where steam or hot water is employed.

The heat which the water attains, renders it necessary to raise, by a small forcing-pump, the injection-water from a well or brook; and the quantity thus raised is more than sufficient to supply the waste by evaporation.

From local circumstances, the pentrough of this engine is comparatively small, being 10 feet long, 5 feet broad, and 5 feet deep. This is a disadvantage to the proprietor: for had it been a large reservoir, or pond, as is the case with an engine erected on this principle for Mr. Lane, near Coventry, it would have raised in two

days a sufficient quantity of water to have kept the wheel at work on the third day without the assistance of the engine.

We deem it necessary to state these particulars, not that it will interfere with the calculations as to the consumption of fuel necessary to produce a given effect, but as a guide to others in the erection of a similar engine. For it is well known that the resistance opposed to the motive power is seldom equal to what it is calculated to perform; and therefore as the engine raises the same quantity of water, whatever may be the discharge at the pentrough, the surplus will be collected in the reservoir.

It may be stated as a recommendation of this engine, that, independently of the simplicity of the construction, it is, from the small number of rubbing surfaces, so little liable to be deranged, that one which has been erected on this principle, and been in use twenty-eight years, exhibits very little injury from wear and tear.

Mr. Keir considers it to have been a profitable engine to himself, and has no doubt that it will prove beneficial in many situations where coal can be obtained at a low price. The average consumption is about four bushels of good coal in twelve hours, when the engine is in the best condition, and about five bushels when at the worst*. The average performance may be fairly rated at 10 lifts per minute, each throwing 7 cubic feet of water into the pentrough, 22 feet above the reservoir: this equals 17,325,000 lbs. raised one foot high by the consumption of each bushel of coal.

* We have been very particular in ascertaining the performance of this engine, from Mr. Keir, as well as from the person who has attended to it upwards of twenty years; and we state this, because Mr. Nicholson, in the Philosophical Journal, has given six and seven bushels for the consumption, and twenty feet for the height to which the water was raised; and this account has been inadvertently copied into the Cyclopædia of Dr. Rees.

This statement will to many appear surprising, as the performance is certainly much greater than could have been expected from any engine constructed on Savery's principle; but this arises from the very judicious introduction of the air-valve before noticed.

An increase of one-eleventh of the preceding effect may also safely be calculated upon in engines hereafter erected on this principle, as the pipe might have been made two feet higher without an additional consumption of fuel. This was not accomplished in the present instance, from prudential motives: being the first of the kind, Mr. Keir resolved not to destroy the probability of success by calculating too closely.

In applying the water which has been raised to produce a rotatory motion, one-third of the power must be deducted, as the maximum effect of a water-wheel cannot be estimated to exceed from two-thirds to three-fourths of the power expended. Deducting, therefore, one-third of the original power, we have 17,325,000 — 5,775,000 = 11,550,000, which is equal to the best engines on the principle of Newcomen: so that had Captain Savery, instead of proposing to drain the mines by erecting engines at several stations or by several lifts, introduced it in this form, and applied pumps to the axis of the wheel, the obstacles which prevented the adoption of his engine would have been successfully overcome.

Economy as to fuel is the grand desideratum in steam-engines. We shall, therefore, in this place, introduce a few observations bearing upon this important point, with which we have been favoured by Mr. Keir.

It has been customary, of late years, to make the fire-places of engine and other boilers very small in proportion to the mass of

matter to be heated, under the idea that the fuel cannot be wasted by the attendant furnishing the grate with too abundant a supply; but the consequence is, that, in order to obtain the necessary degree of heat, the draft must be made very strong, so that the ignition or combustion of the coal is carried on to that extent, which requires fresh quantities of fuel to be continually supplied. This is productive of the following disadvantages:—First, there is scarcely a possibility of admitting, in a *small* grate, a sufficient quantity of atmospheric air to effect the combustion of the gaseous fluids, which are almost instantaneously distilled from the fresh supplies of fuel; a very large portion, therefore, escapes unconsumed through the flue of the chimney, producing not only a considerable loss to the proprietor, but a great nuisance to the surrounding neighbourhood. Second, when the combustion of mineral coal is effected by very rapid drafts, the heat produced is such, that a large portion of the ashes is converted into scoriæ, or imperfect glass: of course oxygen is absorbed and combined, forming a vitreous mass at the expense of fuel. To remove the scoriæ, and supply the fire with fresh fuel, the grate door must be frequently opened, which permits the cold air to rush in, and thereby very materially retards the heating of the boiler. Third, where such intense heats are applied, the fire-bars, the sides of the furnace, and the bottom of the boiler, are very rapidly destroyed.

On the contrary, it may be observed, that when the fire-places are made larger, the destruction of materials is not so rapid, and fuel of a less expensive kind may be advantageously used. In the engine just described, the bars of the fire-grate were 3 feet long, and covered a space 2 feet 6 inches wide, which, for an engine of

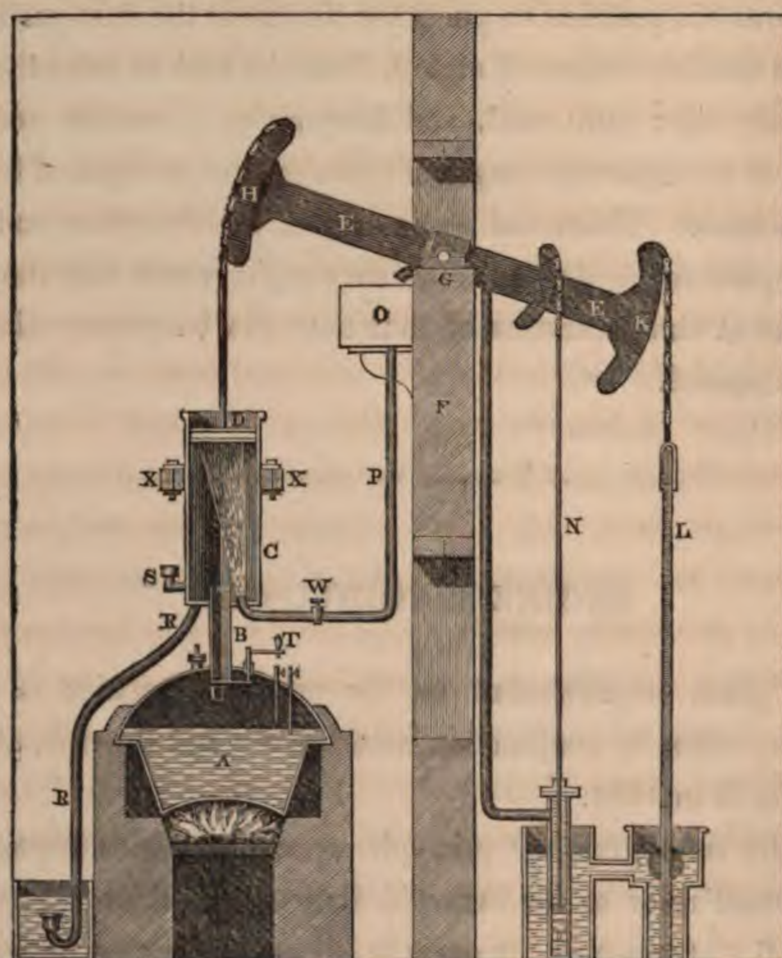
this size, is much greater than is commonly allowed. But from constructing the fire-place on this principle, Mr. Keir found, that he could profitably mix with his coals the whole or the greater part of the ashes that were produced at his forge-fires, and when these failed, it was his practice to purchase cinders at the dust-yards. He also found another source of saving, from the fuel so mixed burning more slowly than pure coal, and keeping up a steadier and more regular heat for a greater length of time, so that it required but very little attendance. From the same cause, the fire-place and boiler did not require repair during the twenty-eight years that they were in use, and at the expiration of that time the bars were taken out very little injured.

ENGINE BY NEWCOMEN.

THE first great improvement on the original machine is that of Newcomen, who, in conjunction with Savery and Cawley, obtained a patent for it in 1705.

To render intelligible the principle upon which this improvement rests, we must refer to the annexed diagram, in which A represents a boiler; B a steam-pipe, or passage of communication between the boiler and cylindrical chamber C; and D a plug or piston, fitted to the interior of the cylinder, but movable in it. E is a lever or beam, supported by the wall F, and vibrating on a centre, at G, having arcs of circles, H and K, at its extremities, for suspending the piston D, and pump-rod L. There is another arc, concentric with the pre-

ceding, to sustain the rod N of the forcing-pump. These arcs of circles, or, as they are technically termed, arch-heads, support the several rods in a vertical direction during the reciprocating motions of the beam.



O is a cistern of cold water, called the injection-cistern; from the lower part of which a pipe, P, descends, and is inserted into the bottom of the cylinder C. R is a pipe called the sink-pipe, proceeding from the cylinder to the hot-well; and at the sides near the bottom of the cylinder there is another pipe, S,

turning upwards; it is closed by a valve called the snifting-valve, which is surrounded by water, contained in a cup, to keep it air-tight.

When the temperature of the water in the boiler has been raised to ebullition, and a sufficient quantity of steam collected, it will be observed to escape at the safety-valve, which is loaded with a weight of one or two pounds per square inch. The elasticity of the steam which is confined in the boiler must, therefore, exceed by that quantity the weight of the atmosphere. The attendant, by the handle T, now removes the regulator U, from beneath the steam-pipe, which allows the steam to rush from the boiler into the cylinder. Being specifically lighter than air, it ascends to the top, and expels a portion of the air which the cylinder contained, through the snifting-valve S. By passing through the air, however, and by contact with the cold sides of the cylinder and the under surface of the piston, a considerable portion of the steam is condensed. But when the piston and cylinder have attained the temperature of boiling water, no further condensation takes place: hence the steam, increasing in elasticity, acquires sufficient force to issue through the snifting-valve. The discharge at first is slow, and of a cloudy appearance, from the steam being mixed with the remaining portion of the air contained in the cylinder; but as it continues, the blast becomes stronger, and the steam more and more transparent. This discharge is allowed to continue until the steam is observed again to make its escape at the safety-valve. For, from what we have said, it must be evident, that, on the admission of steam into the cylinder, the boiler was relieved from pressure, and, consequently, that the safety-valve closed.

The cylinder being now filled with pure steam, the attendant turns the regulator over the orifice of the steam-pipe, and closes the communication between the cylinder and boiler. Then, turning the cock W, the weight of the water in the pipe P, aided very soon by the pressure of the atmosphere on the surface of the water in the cistern O, produces a jet within the cylinder, which, dashing against the piston, is dispersed in drops, and thus produces an *almost* instantaneous condensation of the steam.

By this condensation a vacuum is produced, and the atmosphere presses unresisted upon the upper surface of the piston. If the vacuum is nearly perfect, this pressure will be about 14 pounds per square inch. Therefore, the piston, supposing it to be 36 inches in diameter, will raise, during its descent, a weight of between 6 and 7 tons suspended from the arch-head K, at the other extremity of the beam. In practice considerable allowances must necessarily be made. The weight of the pump-rods causes the beam to preponderate towards K L, and other deductions must be made for the imperfect state of the vacuum, and the inertia, and friction of the several parts.

In consequence of this preponderancy, and the great load in the pumps, there is an interval of about one-third of a second between the opening of the injection-cock and the descent of the piston; and as the atmosphere presses equally in every direction, an attentive observer may perceive a sensible elevation of the cylinder. This arises from the partial vacuum at first produced within the cylinder allowing the atmosphere to press from below, and drive it towards the piston. It is, therefore, necessary, not only to sustain the weight of the cylinder upon the cylinder-beams X, but to secure it firmly against the tendency to ascend.

When the vacuum is sufficiently perfect for the pressure of the atmosphere on the piston to exceed the load in the pumps, and the inertia of the several parts, the piston begins to descend. After it has descended a certain distance, the attendant closes the injection-cock; and when it arrives within a few inches of the bottom, he again removes the regulator from the orifice of the steam-pipe. The steam having, since the communication was closed, been rapidly accumulating, now rushes with violence into the cylinder, and being from one to two pounds stronger than the atmospheric pressure, expels a portion of the remaining vapour through the snifting-clack. It also enables the water of the former condensation to descend, by its weight, into the sink-pipe, and thence through the valve at the extremity of the pipe into the hot well.

The temperature of this water is found to range between 142° and 174°, which may be considered as a fair indication of the heat of the cylinder. By reference to the Synopsis, page 19, it will be observed, from the results of Dalton's experiments, that at the temperature of 150°, which we shall consider as the general heat of the condensed steam, water yields vapour capable of sustaining 7·42 inches of mercury, which is nearly equal to one-fourth of the pressure of the atmosphere: the atmosphere consequently can only press with about three-fourths of its weight upon the piston.

On the re-admission of steam, the counter-weight draws the piston upwards. At that instant, too, the steam does more than counterbalance the pressure of the atmosphere. But during the ascent, successive portions of the cylinder come in contact with the steam; and the quantity thus wasted, as we have before stated, is consider-

able. It varies in different-sized engines from three-fourths to three times as much as that which is necessary to produce the effective power.

Independently of the advantages thus resulting from the counterweight, and which renders it unnecessary to employ steam of greater pressure than one or two pounds per square inch, it is otherwise serviceable in overcoming the friction, and in returning the pump-buckets to the bottom of their respective barrels. This requires force, for the area of the waterway through the buckets is much less than the area of the pump-barrels, consequently the velocity of the issuing water must be in the proportion of the area of the pump-barrels to the area of the buckets.

Before we conclude the description of this engine, it may be necessary to observe, that water contains air in a state of chemical union. This air is very prejudicial to the operation of the engine; and care should be taken to select such water for the boiler and injection-cistern as contains the smallest quantity. Spring water, and water from deep mines, possess much air: the water from running brooks is perhaps preferable to every other kind. The air thus combined is separated from the water by heat: hence, at every condensation, a small quantity is collected within the cylinder, and is expelled, as before stated, at the snifting-valve, by the re-admission of forcible steam.

Having thus briefly described the structure and operation of the first atmospheric engine, we shall exhibit the improvements subsequently introduced by Beighton, as represented in the next Plate.

ENGINE BY NEWCOMEN, IMPROVED BY BEIGHTON.

PLATE IV.

THE boiler, A, is set in a furnace of brick-work, so contrived that the flame and heated air can pass beneath it, and circulate through the side-flues, *a b*, into the chimney.

Between this boiler and the cylinder C, there is a pipe, or communication, *d*, which can be opened and closed at pleasure by the regulator, *f*.

The cylinder, C, has a piston accurately fitted to it, so that, when moving, it is steam-tight. On the external surface of the cylinder are projections or lugs, *e e*, which supports the cylinder on the beams *g g*, one only of which is shown, the other being removed to exhibit the parts in section.

The piston H, which is adapted to the cylinder, is formed of different materials to make it steam-tight. The lowest piece represents a strong circular plate of iron, the diameter of which is very nearly equal to the internal diameter of the cylinder. Above this, and projecting from it, there is a circular ring, and between it and the cylinder a stuffing of oakum or gaskett, lubricated with tallow, to lessen the friction.

D a lever or beam, strongly framed and braced, and having concentric arcs, similar to those already described, to maintain the rods which are supended from them in a vertical direction.

The pump E is called the jaquette or jack-head, and is employed to force water along the pipe *h*, through the valve *i*, into the air-vessel *k*, whence it is conveyed by the pipe *l*, into the injection-

cistern F. From this cistern proceeds a pipe, *m*, and, at about half its length, is placed the stop-cock *n*, and a little above, a branch-pipe, *p*, the orifice of which projects over the side of the cylinder. The water from *p* falls upon the piston, and is intended to assist in keeping it air-tight.

A circular chamber, 3, surrounds the upper part of the cylinder, to receive the water which may flow over during the ascent of the piston. It is furnished with two pipes, *u* and *v*: the former is called the feed-pipe, supplying the boiler with a portion of the water which has been heated by being in contact with the piston and sides of the cylinder; and the latter allowing the surplus water to flow into the hot-well G.

From the lower part of the cylinder proceeds a small pipe, *t*, furnished with a cup and valve, called the snifting-valve; and from the feed-pipe a small branch descends nearly to the cup, for the purpose of supplying it with water. From the top of the boiler proceeds a horizontal pipe, having a loaded valve, 21, connected with a small cord passing over a pulley. By means of this cord, the attendant raises the valve, to allow the steam to escape when the engine ceases working.

The movement of the regulator, instead of being effected by the hand, as in the original engine of Newcomen, is produced by a series of ingenious contrivances. The valve is connected with a vertical spindle, *x*, and a horizontal lever, *y*, Fig. 2, similar to that described in Plate I.; but the rod, *z*, instead of being moved by the hand of the attendant, is impelled so as alternately to cover and uncover the extremity of the steam pipe. To effect this, the upright post, I, supports one end of a horizontal iron axis, marked 1; the other end

of it, being supported by another post, can only be seen at K, Fig. 2. From this axis is freely suspended, by two rings, 2 and 3, a kind of stirrup, formed of two parallel bars of iron, 4 and 5, and a cross-bar, 6, together somewhat resembling the letter H. Above this is another cross piece or spindle, 7, which, passing through the eyes of the fork, 8, connects the rod, *z*, of the lever *y z*, with the stirrup. As this stirrup is freely suspended, the horizontal axis, 1, may be made to revolve in either direction, without communicating its motion to the stirrup, which will remain suspended vertically beneath it, unless force be applied to remove it either to the right or left. It is shown removed to the left in the plan, Fig. 2, and section, Fig. 1.

On the same horizontal axis, 1, is fixed a piece of iron, 9, having at one end a fork, 10, and at the other, a lump of iron or lead. This piece is called the Y, from its resemblance to that letter inverted; and is so placed on the axis, 1, that one of the prongs is situate on each side of the stirrup. The space or distance between the prongs is rather more than sufficient to allow the tail of the Y to be placed upright, without removing the stirrup 6, Fig. 1, when it inclines either to the right or left. In the present position of the engine, the stirrup, 6, is represented to the left of the upright post, I, and the regulator covers the orifice of the steam-pipe *d*. Let, therefore, the Y be raised from its inclined position, and placed on the opposite side of the post with a sufficient inclination for the weight, or, as it is termed, the logger-head or tumbling-bob, at the end of the Y, to descend by its gravity; then, releasing it from the hand, it will descend with considerable force, and, with a smart jerk, place the stirrup, 6, to the right of the post. This jerk is very efficacious, as it instantly overcomes the cohesion and friction of the regulator with the orifice of the steam-

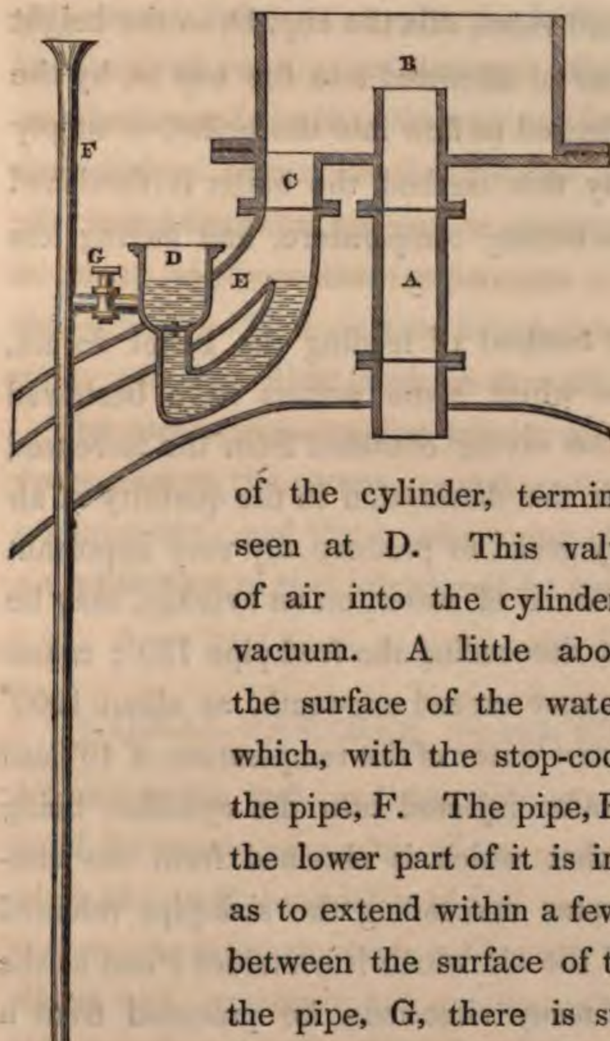
pipe, *d*. The Y is prevented falling too far by a cord or strap, *o o*, which is fastened to the loggerhead and to the cylinder-beam, *g*. By lengthening or shortening this strap, the fall of the loggerhead can be regulated to any required distance.

Having thus exhibited the manner in which the Y influences the regulator, it only remains for us to observe, that by the reciprocation of the beam, D, an alternating motion is given to the plug-tree, L. This plug-tree is formed of two parallel pieces, as represented in the Plan, Fig. 2, to admit two bent handles, called spanners, which are fastened on the same horizontal axis as the Y, to move between them. In the alternating motion of the plug-tree, the spanners, 19 and 20, are struck by pins, which are placed horizontally, as may be seen by reference to the Plan. By means therefore of these contrivances, the loggerhead is jerked alternately to the right and left of the upright post, and the steam-valve is opened and closed at the proper intervals.

In a similar manner the movement of the cock which regulates the injection is effected. To the beam, *g g*, is fastened a bar, *o*, from which is suspended the piece, 13, 14, 15, called the hammer, or more commonly the F, from its resemblance to that letter. It consists of a lump of metal, 13, a fork, 14, and a long tail or spanner, 15. By the movement of the plug-tree, a pin raises the horizontal bar, 16, 17, and releases the head of the F from the catch by which it is supported; it therefore descends with considerable force, and causes the fork, 14, between the prongs of which is the arm, *w*, to open the injection-cock. On the descent of the plug-tree, another pin depresses the tail, 15, of the F, and replaces the head in the catch 16. By this movement the injection-cock is gradually closed; which is necessary, as otherwise the warmth of

the cylinder would be apt to impair the vacuum by reconverting a portion of the water into steam.

Beside the manner of supplying the boiler exhibited in Plate IV., Mr. Beighton introduced another and a better mode, represented in the annexed engraving.



A, the steam-pipe; B, the lower part of the cylinder; and C, the sink-pipe. The sink-pipe here branches into two divisions: the one marked E leads to the hot-well; and the other, being perpendicular to the bottom of the cylinder, terminates in a cup and valve, seen at D. This valve prevents the admission of air into the cylinder, on the formation of the vacuum. A little above the valve, but beneath the surface of the water, a short pipe is inserted, which, with the stop-cock, G, connects the cup with the pipe, F. The pipe, F, is open at both ends, and the lower part of it is introduced into the boiler, so as to extend within a few inches of the bottom; and between the surface of the water in the boiler and the pipe, G, there is sufficient space to admit of the elevation of the water by the pressure of the steam. In Newcomen's engines, the elasticity of the steam rarely exceeded the atmospheric pressure by more than 2 lbs. per

square inch. This is equal to the support of a column of water from 4 to 5 feet high; consequently not less than 5 feet should be allowed between the surface of the water and the orifice of the pipe, G.

When the water descends from the cylinder, it falls into the elbow-pipe, and, raising a small valve, fills the cup, D, to the height of the angle, E; and the water so admitted into the cup is, by the adjustment of the cock, G, allowed to flow into the boiler, to supply the waste of evaporation. By this method the boiler is furnished with water much nearer the boiling temperature, and having less air in combination with it.

Both this and the former method of feeding the boiler do not, however, deserve the praise which some writers have bestowed upon them; for neither is the saving obtained from the increased temperature of the water, nor the diminution in the quantity of air combined with it, sufficiently great, to produce any very important effects. The natural temperature of water, on an average, may be supposed to be 40°, and that descending the feed-pipe 150°; consequently the saving in fuel cannot exceed one-tenth, as about 1200° of heat are necessary to convert water of the temperature of 40° into steam. The quantity of water injected into the cylinder, being eleven times greater than that which is obtained from the condensed steam, leaves the water descending the sink-pipe released of only one-twelfth part of the air which it contained; and as the injection water cannot, in many situations, be procured from a rivulet or brook, it is drawn from the mine. Such water is, in general, so very corrosive as to do the boilers more injury in three months than would have been produced by rain or soft water in as

many years. Mr. Smeaton therefore advised, with propriety, that the whole of the heated water should be allowed to descend the sink-pipe into the hot-well; and that within the last-mentioned a cistern of tin, copper, or other conducting substance, should be placed to receive rain water from an artificial reservoir: this reservoir to be sufficiently large to supply the boiler with water in the interval between rains and great showers. By this means, and by conducting the water from the reservoir to the cistern through a leaden or copper-pipe, surrounded by another pipe, through which the surplus water from the hot well is conveyed, the water in the cistern is raised nearly to the temperature of that which descends from the cylinder. This cistern, being connected, by a pipe and stop-cock, with the boiler, furnishes it with the requisite supply.

The atmospheric engine continued to bear this form for many years prior to the patent granted to Mr. Watt, and even some years subsequently; and the hand-geering of the improved engines is but a modification of that introduced by Beighton.

GENERAL REMARKS ON THE ENGINE OF NEWCOMEN.

Although the form and principle of the atmospheric engine continued for many years the same, many judicious alterations were made in it, and especially in the proportions of its parts. In this respect the labours of the celebrated Smeaton deserve to be examined with attention; but as this will lead to an investigation of the quantity of fuel consumed in producing a given effect, we must first point out the manner in which the power of the engine it computed.

The power of the engine is found by ascertaining, first, the area of the piston; and, secondly, the state of the vacuum; or, in other words, what portion of atmospheric pressure is exercised upon the piston.

1. To find the area of the piston or cylinder, multiply the square of the diameter by ·7854; or the square of the circumference by ·07958; and the product in either case will be the area *.

2. To ascertain the state of the vacuum, find, by a thermometer, the temperature of the condensed steam flowing into the hot-well; then, by reference to the Synopsis, page 16, find the length of the column of mercury which vapour evolved from water at that temperature is capable of supporting: deducting this from the column in vacuo, say 30 inches, the remainder will exhibit the state of the vacuum †.

3. The column of mercury expressed in inches, multiplied into

* 1. *Required the area of a piston whose diameter is 52 inches?*

```
      52
      52
    ----
     104
    260
    ----
    2704
   ·7854
  ------
   31416
  549780
 15708
 -------
```

Answer. 2123·7216 Square Inches.

† *Required the state of the vacuum when the temperature of the water from the sink-pipe is* 150° *?*

By Synopsis, 150° = 7·42 inches; and this, being deducted from 30 inches, leaves 22·58 inches of mercury for the vacuum.

the inches area of the piston, and divided by 2, will give the number of avoirdupois pounds with which the atmosphere presses upon the piston *.

This mode of ascertaining the state of the vacuum may seem circuitous to those who have been accustomed to find it by the barometer, as affixed to the improved engines; but it should be remembered that the barometer cannot so conveniently be applied to the cylinder of the atmospheric engine, where the steam is alternately admitted and condensed, as to the separate condensing vessel introduced by Mr. Watt, where, comparatively speaking, a vacuum always exists.

The preceding rules furnish us with the atmospheric pressure on the piston, but do not, on account of friction and inertia, present us with the actual performance of the engine, correctly expressed by the weight of water raised. This is usually found by multiplying

* 3. Therefore 1. Area of Piston 2123·7216
2. Column of Mercury 22·58

```
     169897728
    106186080
    42474432
   42474432
 2)47953·633728
   23976·816864
```

Or 23977 lbs. nearly.

In cases where great accuracy is not required, it is not necessary to multiply the decimals obtained in the product of the first case: therefore, when the decimals exceed ·5000, let them be considered as a whole number, and added to the integers; but when below that number, the decimals need not be taken into account. In the present example 2124 would have been multiplied by 22·58, and divided by 2; or 2124 would have been multiplied by 11¼.

the cubic feet of water raised at each stroke by 62½, the number of avoirdupois pounds contained in a cubic foot of water *.

There is, however, a much more simple method of determining the quantity of water raised. This is to multiply the area of the

* *Required the performance of an engine, the diameter of the main pump being* 12 *inches, the lift* 61½ *fathoms, and the stroke* 6¾ *feet; and the diameter of the jack-head pump* 8 *inches, the lift* 9½ *fathoms, and the stroke* 5 *feet?*

Diameter of main-pump 12 inches.

```
                          12 × 12 = 144
                                    ·7854
                                   ------
                                    31416
                                   31416
                                   7854
                                 --------
                                 113·0976 area.
61½ Fathoms + 6¾ feet stroke =       4509
                                 --------
                                 10178784
                                56548800
                               4523904
                               ----------
                               509957·0784 content in inches.
                                       62½ lbs.
                               ----------
                      1728)31872317·4000(18444·6
                           1728
                           ----
                           14592
```

Or 18445 lbs. raised by each stroke of the main-pump.

Diameter of Jack-head Pump 8 *Inches.*

$8^2 = 64 \times \cdot 7854 = 50 \cdot 2656$ area in inches.

50·2656 × 9½ fms. and 5 feet stroke = 37397·6064 content in inches.

37397·6064 × 62½ lbs. ÷ 1728 = 1352·6 lbs. raised per each stroke of the jack-head pump.

```
Water raised per main pump 18445
Jack-head pump   -   -      1353
                           -----
                           19798 lbs. the performance, or the disposable power of the engine.
```

main and jack-head pipes respectively by ·434, which is the weight of a column of water 1 inch square and 1 foot high *.

In calculating the power of an engine, it is customary to take into consideration the length of the stroke, the number of strokes made per minute, and the quantity of fuel consumed in a given time; and this is done with the view of comparing the effect with other engines, in order to determine whether the performance be equal to the estimated power. Of this we shall give several examples before we conclude the description of the atmospheric engine.

Although the last of these examples is reduced to its greatest simplicity, it still includes many multiplications, and therefore in practice is liable to error. To obviate this, we shall introduce tables, whereby the saving of much time may be effected, and the answer readily found by addition.

* *Diameter of Main Pump* 12 *inches.*

$12^2 \times \cdot7854 = 113\cdot0976$ area in inches.

$113\cdot0976 \times 61\frac{1}{2}$ fms. and $6\frac{3}{4}$ feet stroke, or $375\frac{3}{4}$ feet $= 42496\cdot4232$

$42496\cdot4232 \times \cdot434 = 18443\cdot4$ lbs.

Diameter of Jack-head Pump 8 *inches.*

$8^2 \times \cdot7854 = 50\cdot2656$ area in inches.

$50\cdot2656 \times 9\frac{1}{2}$ fms. and 5 feet stroke, or 62 feet $= 3116\cdot4672$

$3116\cdot4672 \times \cdot434 = 1352.5$ lbs.

In the first of these there is a slight difference from the similar example in the foregoing note; but as it is only 1 lb. in 18,000, the rule must be sufficiently correct for practical purposes.

By these examples, taken from the actual performance of an engine erected by Mr. Smeaton, it should seem, that though the atmospheric pressure on a 52-inch piston is 23977 lbs.
the effective power of the engine is only - - 19798 lbs.

4179 lbs. being lost in overcoming the friction, inertia, &c.

Table I. *Diameter of the Cylindrical Bore* 1 *Inch.*

Feet High.	Quantity of Water in Cubic Inches.	Weight of Water in Troy Ounces.	Weight of Water in Avoirdupois Ozs.
1	9·4248	4·9712	5·4541
2	18·8495	9·9424	10·9083
3	28·2743	14·9137	16·3624
4	37·6991	19·8850	21·8166
5	47·1239	24·8561	27·2708
6	56·5486	29·8274	32·7249
7	65·9734	34·7986	38·1791
8	75·3982	39·7699	43·6332
9	84·8230	44·7411	49·0874

Table II. *Diameter of Cylindrical Bore* 1 *Inch.*

Feet High.	Quantity of Water in Cubic Feet.	Weight of Water in Troy lbs.	Weight of Water in Avoirdupois lbs.
1	·00545	·4142	·3409
2	·01090	·8285	·6818
3	·01636	1·2428	1·0226
4	·02181	1·6570	1·3635
5	·02727	2·0713	1·7044
6	·03272	2·4856	2·0453
7	·03818	2·8998	2·3862
8	·04363	3·3141	2·7271
9	·04909	3·7284	3.0679

By means of these tables the quantity and weight of water in a cylindrical tube of any given diameter may be found. For though the tables are only calculated for units, the sums for tens, hundreds, and thousands may be found by adding 0, 00, 000, respectively, to the right of the decimal; and multiplying such sums by the square of the diameter of the given bore, the product will be the answer *.

The foregoing examples apply to the effective performance of an engine; but do not give the proportion of the diameter of the cylinder to that of the pump-barrel, or the diameter of the pump-barrel to the quantity of water which is to be raised; we shall therefore give some easy rules, sanctioned by successful practice, to enable the artist to suit the size of his engine to the task which it is to perform. The engine will be supposed to make 12 strokes per minute, each 6 feet long.

1. *To find the Diameter of the Pump.*

Multiply the cubic feet of water which must be drawn in a minute by $2\frac{1}{2}$, and extract the square root of the product, which will be the answer.

* *Required the weight of water raised by the main pump, the diameter being* 12 *inches, the stroke* $6\frac{3}{4}$ *feet, and the lift* $61\frac{1}{2}$ *fathoms?*

$$61\tfrac{1}{2}\text{ fms.} + 6\tfrac{3}{4}\text{ feet stroke} = 375\tfrac{3}{4}\text{ feet}\left\{\begin{array}{rcr} 300 & = & 102{\cdot}2600 \\ 70 & = & 23{\cdot}8620 \\ 5 & = & 1{\cdot}7044 \\ \frac{1}{2} & = & {\cdot}1704 \\ \frac{1}{4} & = & {\cdot}852 \end{array}\right.$$

$$\begin{array}{rr} & \overline{128{\cdot}0820} \\ 12^2 = & 144 \\ & \overline{512{\cdot}3280} \\ & 17931{\cdot}480 \\ & \overline{18443{\cdot}8080} \\ & \overline{\text{or } 18444\text{ lbs.}} \end{array}$$

Thus, suppose that 58 cubic feet must be drawn every minute; 58 multiplied by $2\frac{1}{2}$ gives 145, of which the square root is 12, which is the required diameter of the pump *.

2. To find Diameter of the Cylinder.

Multiply the square of the diameter of the pump-barrel, found by the preceding rule, by the fathoms of lift, and divide the product by 3; the square root of the quotient is the diameter of the cylinder.

Suppose the pit to which the pump is to be applied is 24 fathoms deep; then $\frac{24 \times 144}{3}$ gives 1152, of which the square root is 34 inches, very nearly †.

To relieve the practical engineer as much as possible from all trouble of calculation, Mr. Beighton, in 1717, published the following table of the dimensions and power of the Atmospheric Engine. It exhibits the diameter of the cylinder to that of the pump, for raising any quantity of water from 48 to 440 hogsheads per hour, and at any depth from 15 to 100 yards.

* This rule, by Professor Robison, is founded upon the following investigation:—

Let Q be the quantity of water to be drawn per minute in cubical feet, and f the depth of the mine in fathoms. Let c be the diameter of the cylinder, and p that of the pump; and let us suppose the fulcrum to be placed in the centre of the beam.

To find the diameter of the pump, the area of the piston in square feet is $p^2 \times \frac{0{\cdot}7854}{144}$. The length of the column drawn in one minute is 12×6 or 72 feet, and therefore its solid content is $p^2 \times \frac{72 \times 0{\cdot}7854}{144}$ cubical feet, or $p^2 \times 0{\cdot}3927$ cubical feet. This must be equal to Q; therefore p^2 must be $\frac{Q}{0{\cdot}3927}$, or nearly $Q \times 2\frac{1}{2}$.

† The piston is to be loaded with 7·64 lbs. on every square inch. This is equivalent to 6 lbs. on a circular inch, very nearly. The weight of a cylinder of water an inch in diameter and a fathom in height, is $2{\cdot}\frac{1}{24}$ lbs, or nearly 2 lbs. Hence it follows that $6c^2$ must be made equal to $2fp^2$, and that c^2 is equal to $\frac{2fp^2}{6}$, or to $\frac{fp^2}{3}$.

TABLE BY BEIGHTON.

Proportion of the Cylinder and Pump-Barrel to the quantity of Water to be raised.

Diameter of the Cylinder in inches.

PUMPS.							CYLINDERS.												
							The Depth from which Water is to be drawn. Yards.												
Diameter of the bore.	Will hold in a yard.	Will draw by a six feet stroke.	Weight in one yard.	At sixteen strokes in a minute.	Sixty-three gallons to a hogsh.	In one hour.	15	20	25	30	35	40	45	50	60	70	80	90	100
Inches.	Gallons.	Gallons.	lbs.	Gallons.	H G.	H. G.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
12	14.4	28.8	147.	462.	7 21	440	18½	21¾	24	26½	28½	30½	32½	34¼	37¼	40	43½		
11	12.13	24.26	123.5	388.	6 20	369 33	17	19¾	22	25	26¼	28	29¼	31¼	34½	37	39½		
10	10.02	20.04	102.	320.6	5 5	304 48	15½	18	20	22	23¾	25¼	27	28¾	31¼	34	36	38½	40
9	8.12	16.24	82.7	259.8	4 7	247 7	14	16¼	18	20	21½	23	24¼	25	28	30½	33	35	36½
8½	7.26	14.52	73.9	232.3	3 43	221 15	13½	15¼	17¼	19	20¼	21¾	23	24	26¼	28½	31	32½	35¼
8	6.41	12.82	65.3	205.2	3 16	195 22	12½	14½	16½	18½	19	20½	21	23	25	27	29	30½	32½
7¾	6.01	12.02	61.2	192.3	3 2	182 13	12	14	15½	17½	18¾	19¾	21	22	24¼	26	28	29¼	31½
7½	5.66	11.32	57.6	181.1	2 55	172 30	11	13¾	15	16½	18	19	20	21¼	23¼	25	27	28½	30¼
7	4.91	9.82	50.	157.1	2 31	149 40	10¾	13	14	15½	16¾	18¾	19	20¼	22	24	25½	27	28½
6½	4.23	8.46	43.	135.3	2 9	128 54	10	12	13	14	15½	16¼	18	19	20	22	23	24½	26¼
6	3.61	7.2	36.7	115.5	1 52	110 1	9½	11	12	13	14	15½	16	17	19	20½	22	23	24½
5½	3.13	6.2	31.8	99.2	1 36	94 30		10	11	12	13	14	15	15¾	17	19	20	21	22¼
5	2.51	5.0	25.5	80.3	1 7	66 61			10	11	11¾	13	13¾	14	15½	16¾	18½	19½	20¼
4½	2.02	4.04	20.5	64.6	1 1	60 60				10	11	11¾	12	13½	14	15	16	17	18¼
4	1.6	3.2	16.2	51.2	0 51	48 51					9	10	11	11½	12	13½	14	15	16
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

This Table assumes that the ale-gallon (containing 282 cubic inches), when filled with pure running-water, weighs 10lb. 3 oz. avoirdupois; and that upon each square inch the pressure of the atmosphere is 14 lbs. 13 oz. when the mercury stands at 30 inches in the barometer.

But allowing for much friction, and to give a considerable velocity to the engine, experience has taught us not to estimate the effective power at more than 8 lbs. per inch in the cylinder's area, that it may make about 16 strokes in a minute, at about 6 feet each.*

If the depth of the mine is greater than the highest number contained within the Table, take its fourth part, and double the diameter of the cylinder. Thus, if 150 hogsheads are to be drawn in an hour from the depth of 100 fathoms, column 7 gives for 149.40 a pump of 7 inch bore. In a line with this, under the depth of 50 yards, which is one-fourth of 100 fathoms, we find 20½, the double of which is 41 inches for the diameter of the cylinder.

In order to determine the best proportions of the parts of Newcomen's engine, Mr. Smeaton made numerous experiments, and the results furnished him with data for the construction of engines of any required power. This important information is contained in the following table.

* *Required the diameter of the cylinder, and of the pump-barrel, to draw* 150 *hogsheads per hour at* 90 *yards deep?*

Find in column 7 the nearest number to the quantity of water to be raised, and against it in column 1 the diameter of the pump-barrel. Then, under the column expressive of the depth from which the water is to be drawn, find the diameter of the cylinder fit for the purpose.

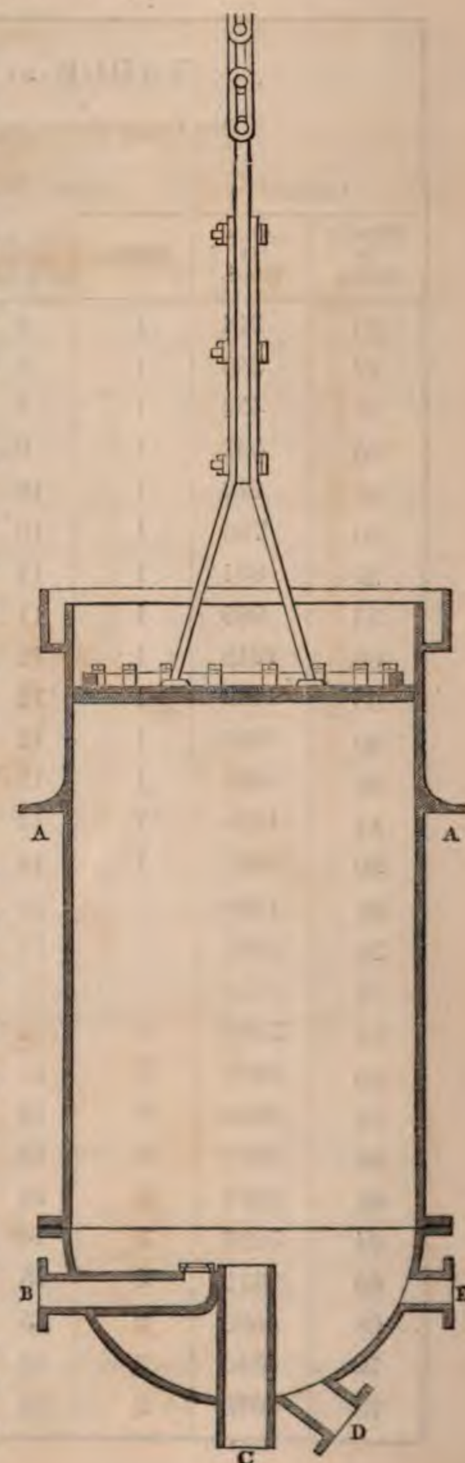
$$\text{150 hogsheads column } 7 = \overset{\text{Hhds.}}{149.40}\begin{cases}\text{Diam. of pump-barrel, col. } 1 = 7 \text{ inches.}\\ \text{Diam. of cylinder, col. } 19 = 27 \text{ inches.}\end{cases}$$

TABLE BY MR. SMEATON.

For Proportioning the Parts of Newcomen's Engine.

Cylinder		*Boiler.*		*Steam-Pipe.*	*Injection.*	*Stroke.*	
Diameter in inches.	Area in inches.	Number.	Centre-Diameter in ft. & inches.	Diameter in inches.	Square hole in inches.	Length in ft. & inches.	Number per minute.
20	314	1	8	$3\frac{3}{4}$	$\frac{1}{2}$	4 8	$15\frac{1}{2}$
22	380	1	8 6	4	$\frac{9}{16}$	4 10	$15\frac{1}{4}$
24	452	1	9	$4\frac{1}{4}$	$\frac{3}{5}$	5	15
26	531	1	9 6	$4\frac{1}{2}$	$\frac{2}{3}$	5 2	$14\frac{3}{4}$
28	616	1	10	5	$\frac{11}{16}$	5 4	$14\frac{1}{2}$
30	706	1	10 6	$5\frac{1}{4}$	$\frac{3}{4}$	5 6	$14\frac{1}{4}$
32	804	1	11	$5\frac{1}{2}$	$\frac{3}{4}$	5 8	14
34	908	1	11 6	$5\frac{3}{4}$	$\frac{13}{16}$	5 10	$13\frac{3}{4}$
36	1018	1	12	$6\frac{1}{4}$	$\frac{7}{8}$	6	$13\frac{1}{2}$
38	1134	1	12 6	$6\frac{1}{2}$	$\frac{15}{16}$	6 2	$13\frac{1}{4}$
40	1256	1	13	$6\frac{3}{4}$	$\frac{15}{16}$	6 4	13
42	1385	1	13 6	7	1	6 6	$12\frac{3}{4}$
44	1520	1	14	$7\frac{1}{2}$	1	6 8	$12\frac{1}{2}$
46	1662	1	14 6	$7\frac{3}{4}$	$1\frac{1}{16}$	6 10	$12\frac{1}{4}$
48	1809	1	15	8	$1\frac{1}{8}$	7	12
50	1963	2	11	$8\frac{1}{2}$	$1\frac{3}{16}$	7 2	$11\frac{3}{4}$
52	2124	2	11 6	$8\frac{3}{4}$	$1\frac{1}{5}$	7 4	$11\frac{1}{2}$
54	2290	2	12	9	$1\frac{1}{4}$	7 6	$11\frac{1}{4}$
56	2463	2	12 6	$9\frac{1}{2}$	$1\frac{1}{4}$	7 8	11
58	2642	2	13	$9\frac{3}{4}$	$1\frac{5}{16}$	7 10	$10\frac{3}{4}$
60	2827	2	13 6	10	$1\frac{1}{3}$	8	$10\frac{1}{2}$
62	3019	2	14	$10\frac{1}{2}$	$1\frac{6}{16}$	8 2	$10\frac{1}{4}$
64	3216	2	14 6	$10\frac{3}{4}$	$1\frac{3}{5}$	8 4	10
66	3421	2	15	11	$1\frac{7}{16}$	8 6	$9\frac{3}{4}$
68	3632	2	15 6	$11\frac{1}{2}$	$1\frac{7}{16}$	8 8	$9\frac{1}{2}$
70	3848	2	16	$11\frac{3}{4}$	$1\frac{1}{2}$	8 10	$9\frac{1}{4}$
72	4071	2	17	12	$1\frac{1}{2}$	9	9

According to these proportions, Mr. Smeaton, between the years 1774 and 1782, erected several engines in different parts of the kingdom, some of them having cylinders five and six feet in diameter. In general, a considerable saving of fuel was effected.



Independently of a better mode of proportioning the parts, Mr. Smeaton conceived that much advantage would be derived from applying an hemispherical bottom to the cylinder. The cylinder, with the piston contained in it, is represented in the annexed diagram.

A represents the projections or lugs, to secure the cylinder to the cylinder-beams; B, the injection-pipe; C, the steam-pipe, leading from the boiler; D, the sink-pipe, leading to the hot-well; and E the snift-pipe. The other parts explain themselves. The lower surface of the piston used by Mr. Smeaton was always planked with elm or beech, about $2\frac{1}{4}$ inches thick, to prevent the radiation of heat. The planking consisted of

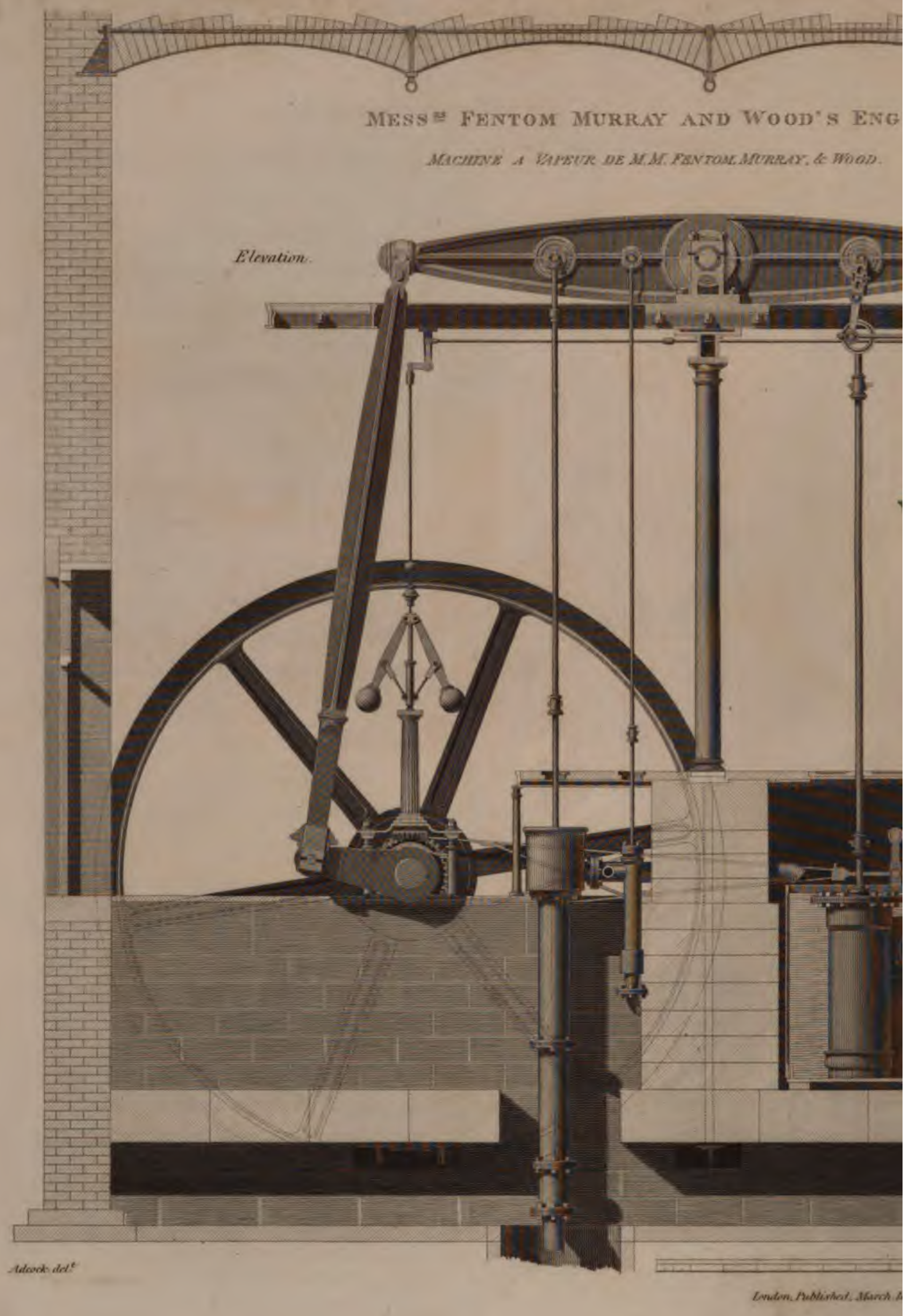
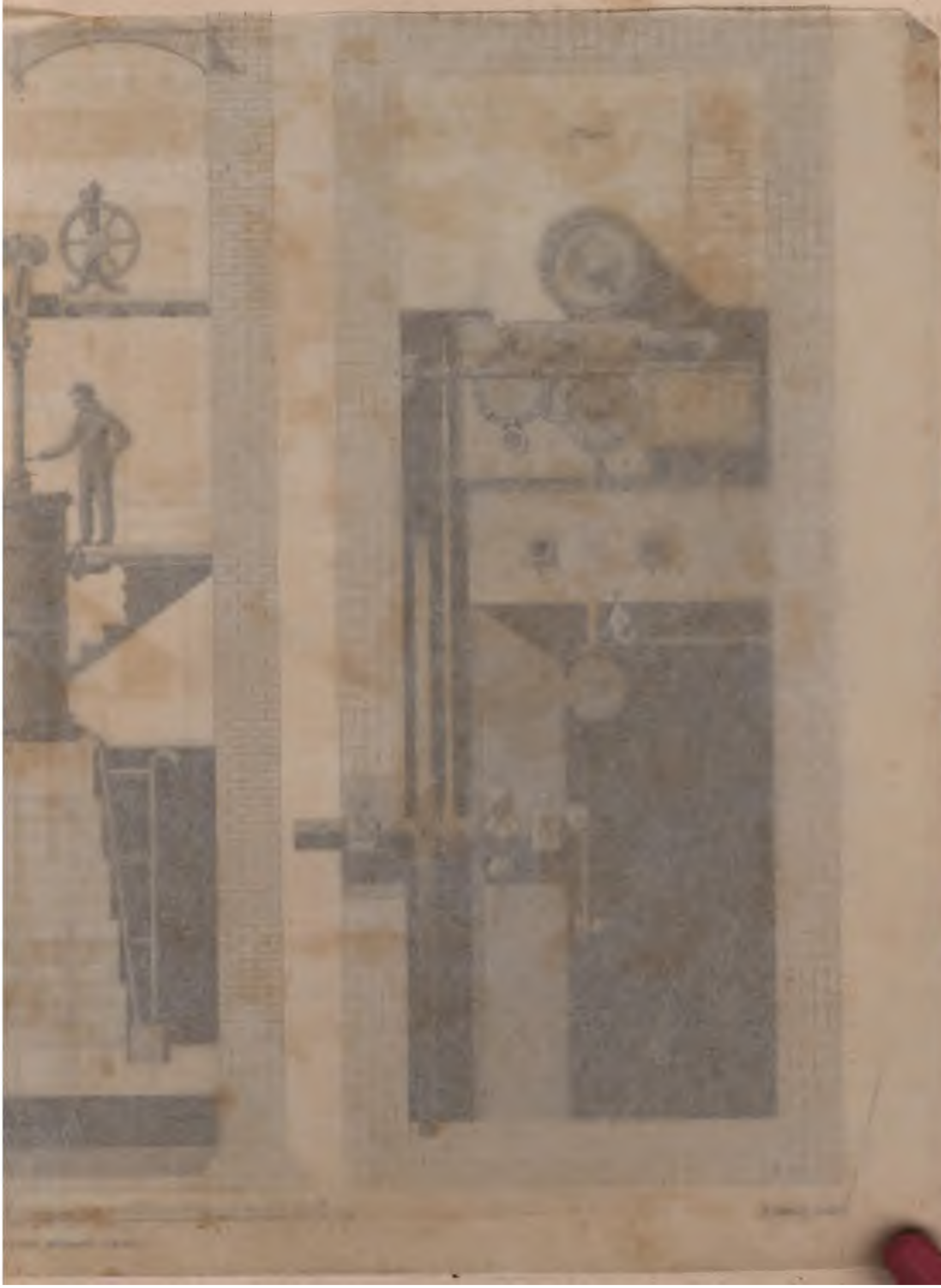
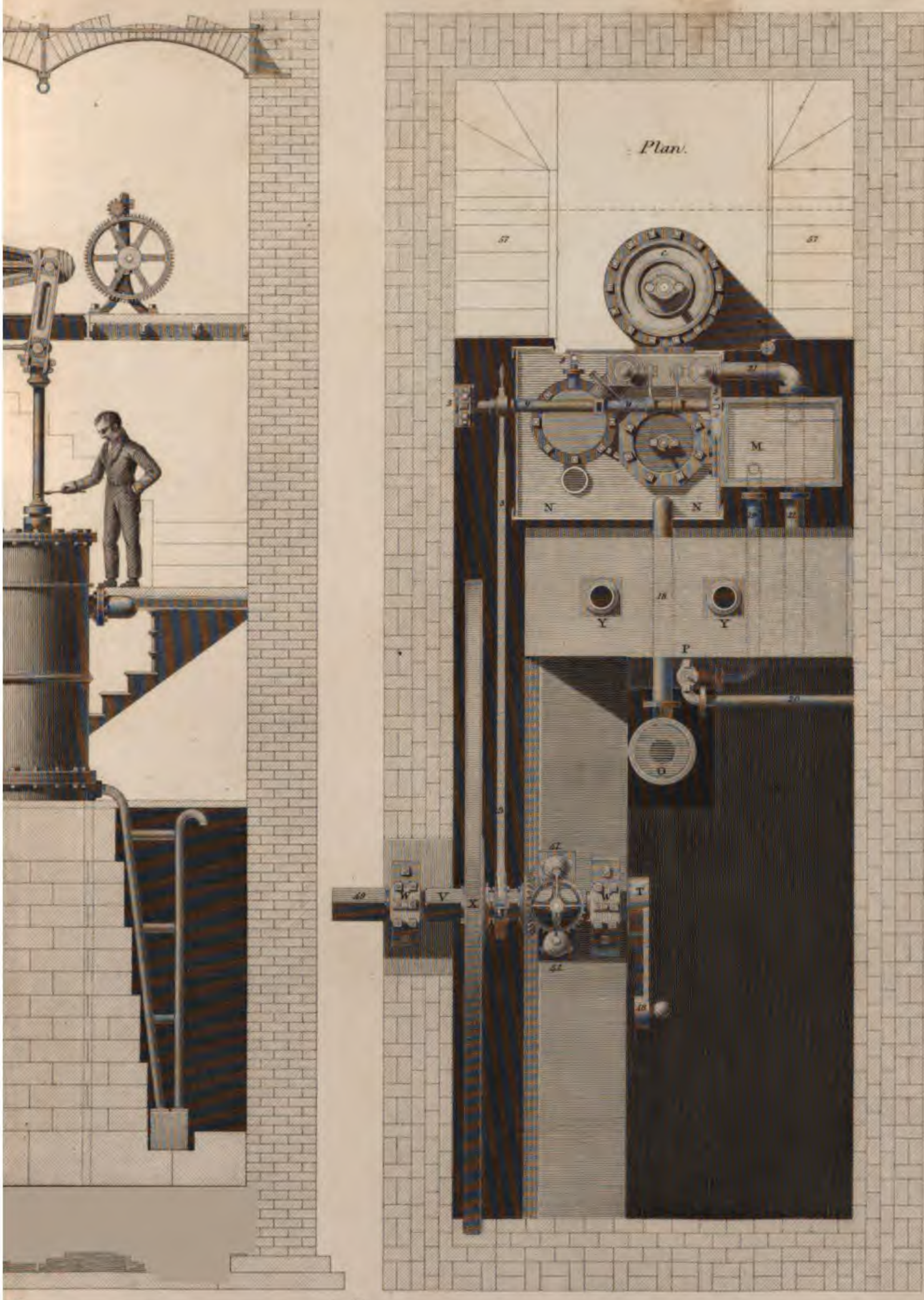

MESS^RS FENTOM MURRAY AND WOOD'S ENG
MACHINE A VAPEUR DE M.M. FENTOM, MURRAY, & WOOD.
Elevation.
Adcock del^t
London, Published, March

PLATE XIV





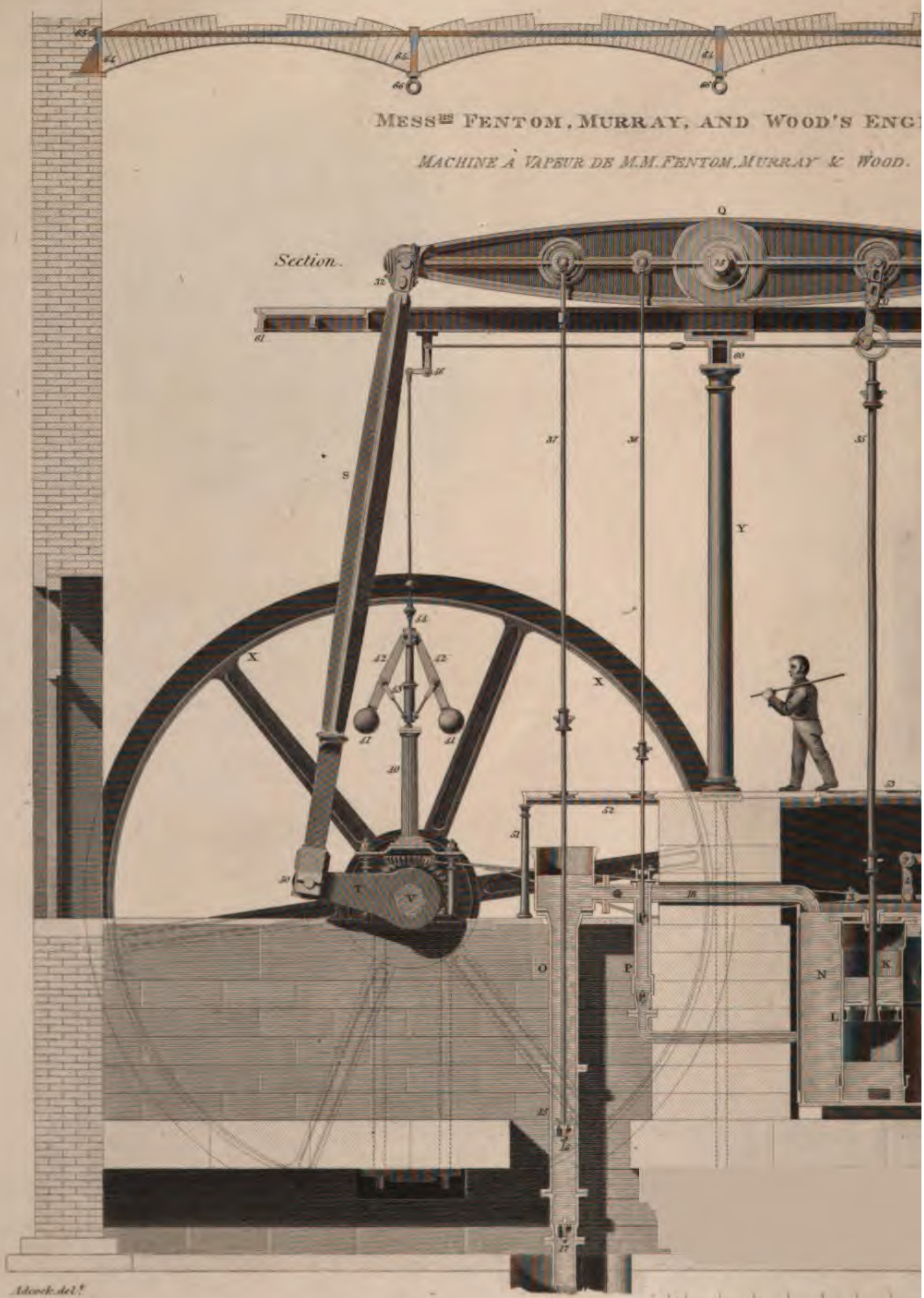
Feet

E. Turrell. sculp[t]

Murray, Albemarle Street.

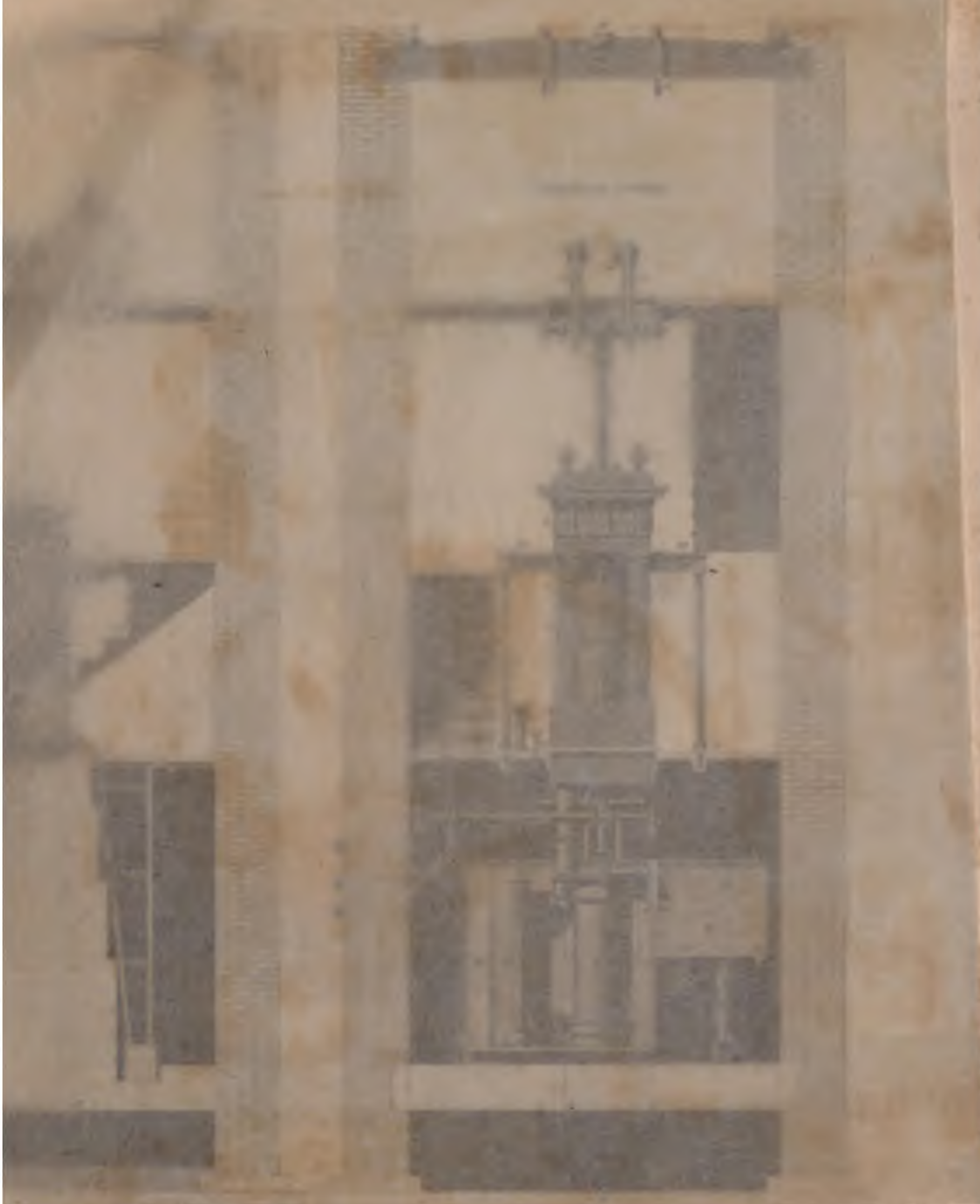
MESS.RS FENTOM, MURRAY, AND WOOD'S ENG

MACHINE À VAPEUR DE M.M. FENTOM, MURRAY & WOOD.



Adcock del.t

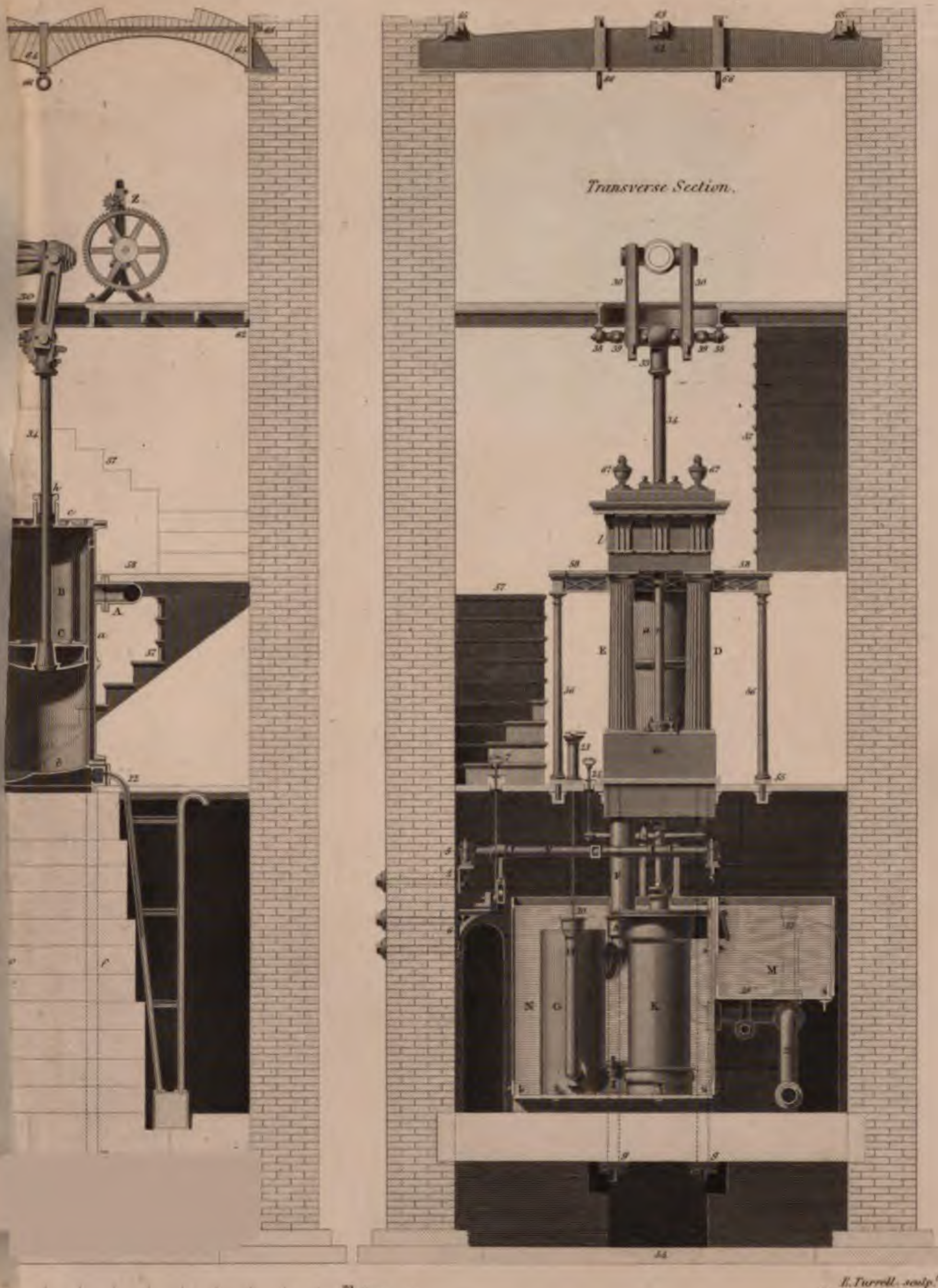
London, Published March 182



Turrell, sculp.

Street.

London, Published March 1827



E. Turrell, sculp.t

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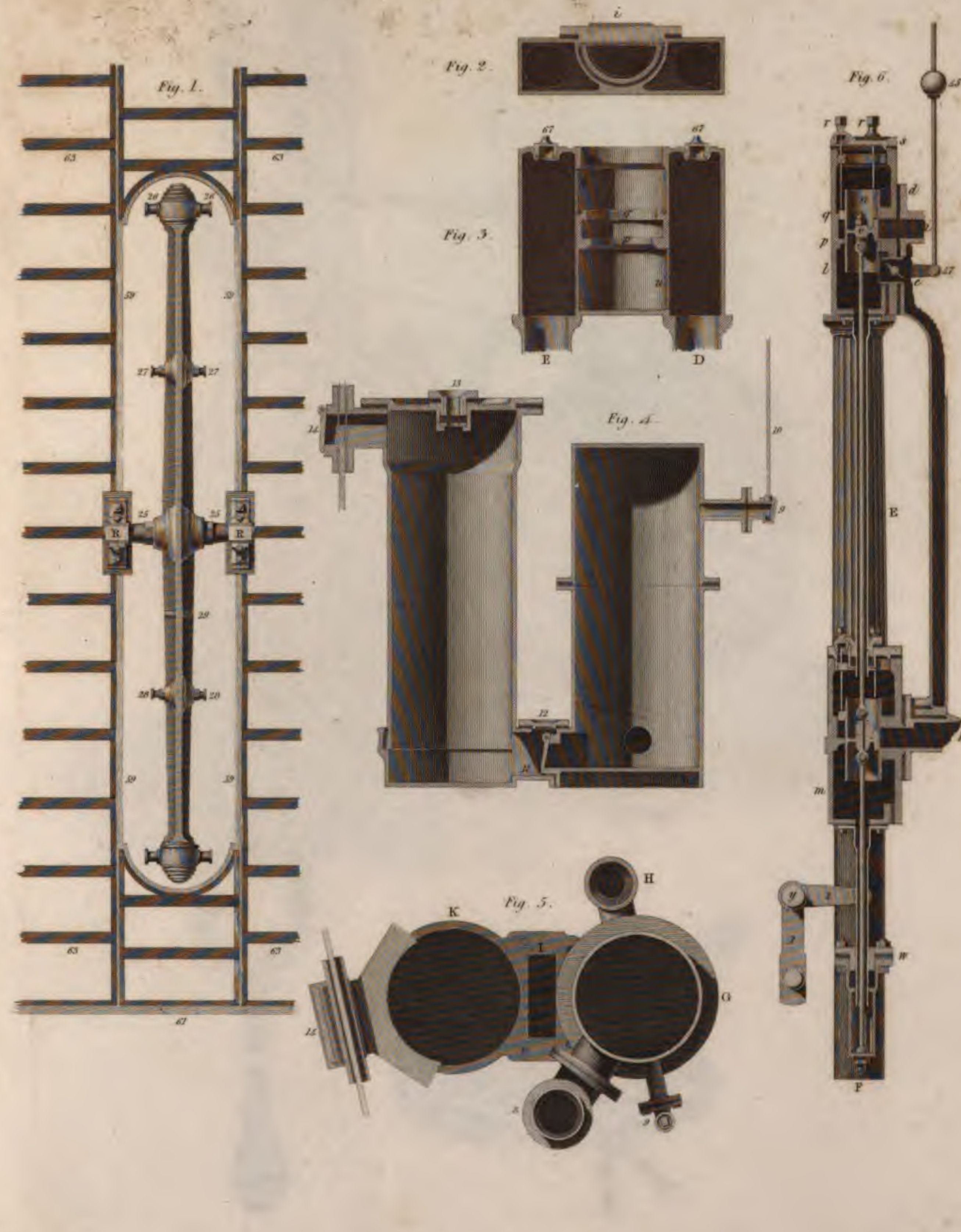
MESSRS FENTOM MURRAY AND WOOD'S ENGINE. PLATE XVI.

MACHINE À VAPEUR DE M. M. FENTOM, MURRAY, & WOOD.



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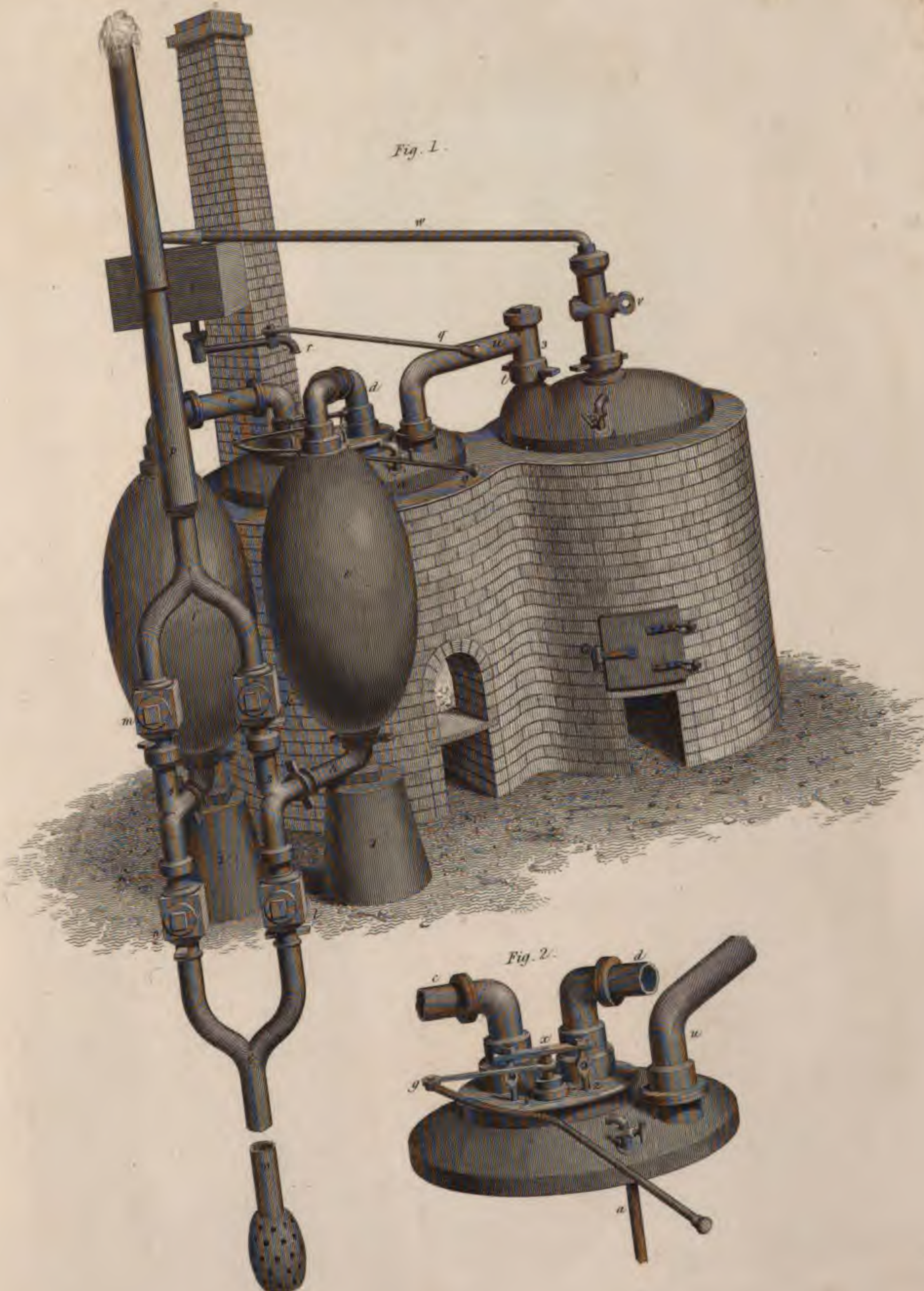
STEAM-ENGINE BY SAVERY.

MACHINE À VAPEUR DE M. SAVERY.



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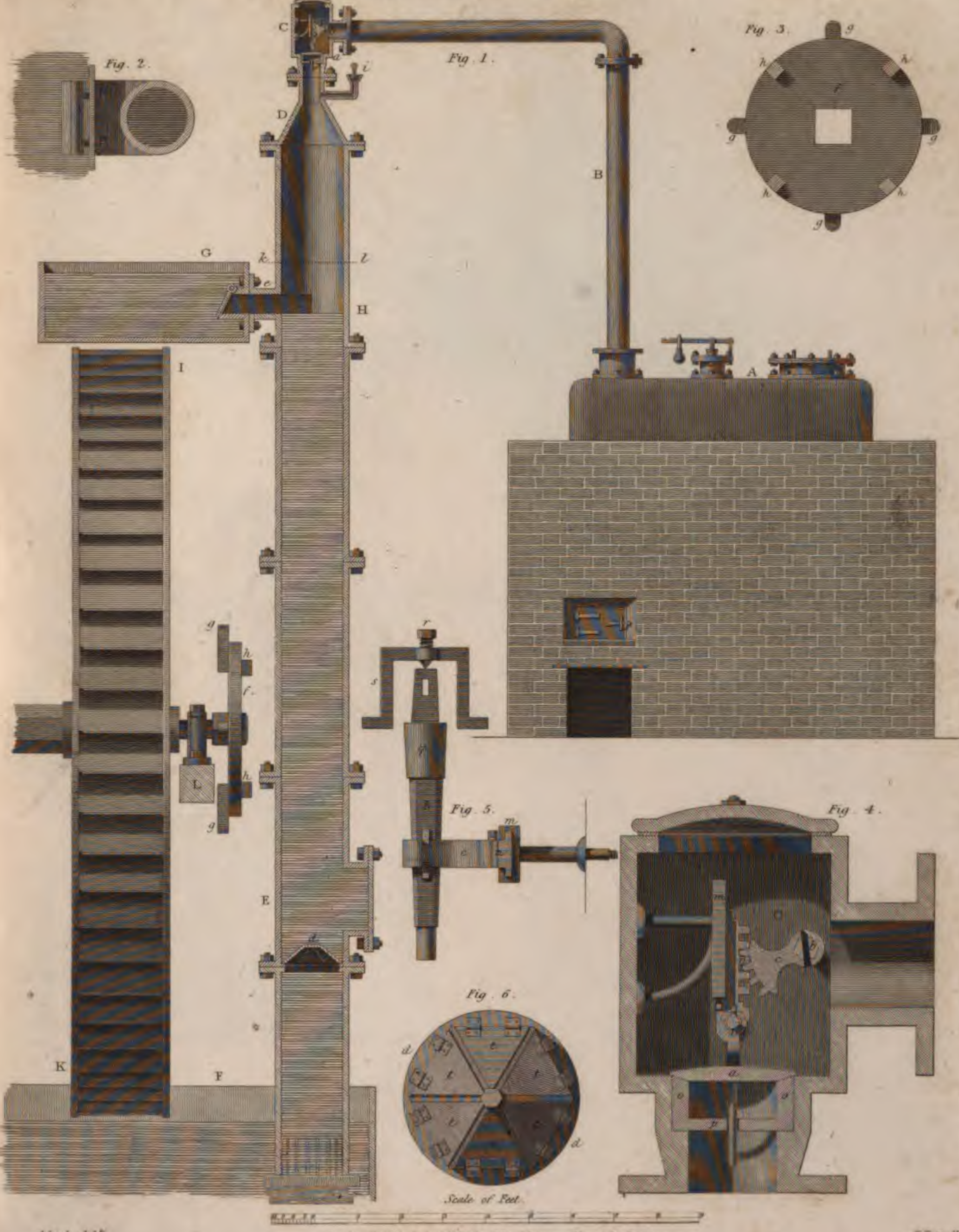
M^r. PETER KEIR'S ENGINE.

PLATE III.

MACHINE À VAPEUR DE M. P. KEIR.



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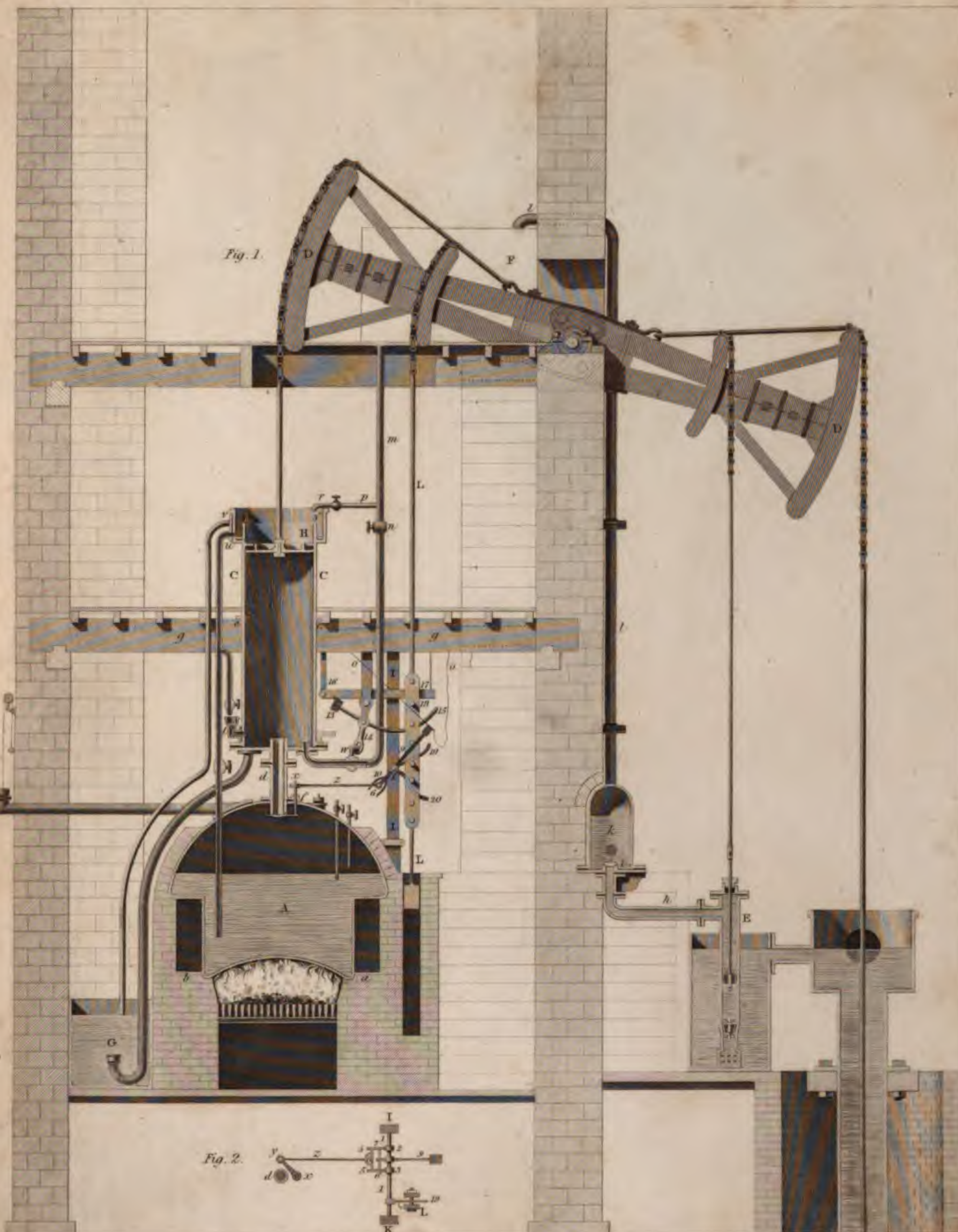
STEAM ENGINE BY NEWCOMEN. PLATE IV

MACHINE À VAPEUR DE M. NEWCOMEN.



Adcock del.t *A. Dick sculp.t*

London Published Feb.y 1827 by John Murray Albemarle Street.

deferred, in consequence of a recent resolution of the Society of Civil Engineers, to institute immediately, under the direction of a select committee, an experimental inquiry into the comparative advantages of condensing and high-pressure engines. An account of the experiments and conclusions of this distinguished association, necessarily including the objects which we had in view, and giving, in all probability, a final decision to this important question, will enable us fully to accomplish the intentions of the dissertation above alluded to.

Although we do not profess to take an enlarged historical view of the origin and progress of the valuable machine which we so minutely describe, yet we propose to notice this subject in a Preface. We shall thus have an opportunity to do justice to the achievements of some of the earlier mechanics, whose merits, by no means inconsiderable, have been scarcely recognised amidst the superior splendour of one great modern improver. Our arrangement will however be found to be thoroughly historical, including only such of the progressive forms as still continue, whether partially or generally, to be employed.

Since engines for steam navigation constitute the most remarkable feature in their present application, they will receive particular attention, and their various modifications will be fully displayed. And near the conclusion of this undertaking, we shall notice, although much more cursorily, numerous alleged improvements, not yet acknowledged by engineers as effective machines, but principally recommended, on account of their peculiar fitness for propelling vessels and carriages, by their sanguine projectors and speculative admirers.

PROSPECTUS.

It is intended that this Treatise on the Steam-Engine shall be completed in Nine Parts; and as each Part will consist of Eight Quarto Plates, printed on the finest paper, and engraved in the most splendid manner, it will, when complete, represent in plan, elevation, section, and detail, the Engines of every celebrated maker.

The THIRD PART is in the Press.

LONDON:
Printed by W. CLOWES, Stamford-street.